A MIXED METHODS EVALUATION OF A STREAM MONITORING CITIZEN SCIENCE PROGRAM

By

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Abstract: The purpose of this 3-article dissertation is to better understand how volunteer experience in place-based and data-rich programs influences their science learning, motivations, and data quality.This mixed methods evaluation consisted of three distinct phases: 1) survey assessment of the impact that participation in Blue Thumb has on individual learning outcomes, such as behavior and stewardship, interest, and motivation, 2) interviews to relate motivation for volunteerism to place-based attachments and 3) a mixed methods analysis relating data quality to participant perception of skill and self-efficacy. There were not significant differences between new and experienced volunteer behaviors and interests, but qualitative results yielded context to results. Volunteers' motivations were significantly different and driven by various categories of attachments to the places being monitored. Lastly, skill and self-efficacy did not correlate to data quality. This research suggests that mixed methods are more informative than survey items alone, as they provide context to quantitative survey scores. Future research will benefit from the inclusion of more robust and inclusive evaluation tools, with consideration to volunteers' individual experiences and rich narratives.

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CHAPTER I

OVERVIEW OF STUDY

Introduction

Citizen science is a growing field of volunteerism and research, with the possibility to change natural resource management and involve the public in ongoing endeavors. The types of participation and evaluation of these programs are an emerging area of study. In particular, the field of citizen science has begun to ask questions such as “who are the volunteers?”, “what are the outcomes of participation?”, and “in what ways does volunteer experience shape desired outcomes?”. In Oklahoma, citizen scientists help to collect water quality data across large spatial and temporal ranges, which may be otherwise unfeasible to achieve and are valuable to state resource management. This section provides the context for this dissertation and explains the relevance of the research for the field of citizen science evaluation.

The Importance of Citizen Science

In recent years, citizen science programs have gained momentum and involved members of the public in active and ongoing science research. Citizen science is often defined as a form of research collaboration that engages members of the public, who are non-professional scientists, in scientific research projects that involve data collection, analysis, and dissemination (Haklay, 2013; Dickinson et al., 2012; Conrad & Hilchey, 2011; Wiggins & Crowston, 2011). Citizen science is an interdisciplinary field that covers many different fields of study and methodologies including analyzing datasets, collecting ecological data, identifying bacteria cultures, mapping constellations, observing animal behavior, and much more (Raddick et al., 2013; Cronje, Rohlinger, Crall, & Newman, 2011; Evans et al., 2005). The goals of citizen science projects can be broad, from collecting data for decision making to the increase of scientific literacy of participants (Bonney et al., 2009b).

Data collected through citizen science projects have been applied to formal scientific studies and resulted in publications, technical reports, and other governmental documentation (Briggs & Krasny, 2013). Although citizen science was conceived as a method for data procurement across large spatial and temporal scales (Phillips et al., 2018; Bonney et al., 2009b), it has also become a widespread form of formal and informal science education (Bonney et al., 2009a; Kridelbaugh, 2016; Mitchell et al., 2017) and is used as outreach to promote public understanding of science (Wiggins & Crowston, 2011).

While citizen science projects have been successful in advancing scientific knowledge and achieving specific research or program outcomes, more focus is now being placed on evaluating the impacts of citizen science on the participants involved (Phillips et al., 2018; Bonney et al., 2009b). Published evaluations of participant outcomes in individual citizen science projects are limited in quantity. While research or program outcomes are often evaluated for reporting purposes and to justify the continuing programs, evaluations of individual or social outcomes are much less common. There are few established indicators or methodologies for evaluating citizen science and there exists an overall lack of consistent definitions and desired categories of participant outcomes. Most published evaluations rely on pre- and post-test self-reported measures. Even less research exists that explores the relationship between participant outcomes and data quality

Citizen science projects are often divided into three distinct categories based on a typology created by The Center for Advancement of Informal Science Education (CAISE): contributory, collaborative, or co-created (Bonney et al., 2009a). A citizen science project can be classified according to the extent to which participants are engaged in the scientific process from developing a research question, to designing methodology, interpreting data, and sharing conclusions. Contributory projects are the most common form of citizen science projects, as they are those that are driven by researchers and supported by volunteers. These projects often involve volunteers who collect large spatial and temporal data for researchers to then interpret and use. In contributory projects, data collection may be the only part of the scientific process that engages volunteers. Collaborative projects engage participants more directly in the process of science. In these projects, researchers define a scientific question and hypothesis that participants can collaborate with them on. Volunteers not only collect the data but may help volunteers to design methodology and analyze the data as well. Finally, co-created projects are those that are driven by participants and supported by researchers. These projects are defined by citizens who develop their own questions, methodologies, and data collection while enlisting scientists to support them. Many papers discuss the significant social and educational outcomes that involved citizen science projects may have on volunteers (Bonney et al. 2009a).

Worldwide, there has been a large focus on citizen science as a tool to enhance monitoring and management of natural resources, track biodiversity and endangered species, and other conservation efforts (Conrad & Hilchey, 2011). Citizen science data has made contributions to the field of conservation in terms of providing information about species behaviors, abundance, and distributions (Briggs & Krasny, 2013). As technology has increased, it has provided even more ample opportunities for environmentally focused citizen science projects to grow. Modern sensors allow amateurs to collect environmental data with the same accuracy of experts, information and communication technologies (ICT) allow the compilation and sharing of collected data, and communication technologies support a dynamic approach to knowledge-sharing (Buytaert et al., 2014).

With improving technology, the ease of monitoring environmental conditions has encouraged advancements in citizen science data collection from digitally uploaded single event sampling data (i.e., iNaturalist) to crowdsourcing large spatial data (i.e., Zooniverse) (Wiggins & Crowston, 2011). Many modern projects and programs contribute substantially to the fields of environmental science by operating at greater geographical and temporal scales than conventional science, speeding up field detection and observations, improving data and image analyses, and refining research questions to aid scientific endeavors (McKinley et al., 2016; Hadi-Hammou et al., 2017; Poisson et al., 2020). These contributions allow natural resource managers to use "best available science" in order to make informed management decisions (McKinley et al., 2016). This type of citizen science serves two functions: informing and involving the public of environmental issues and collecting data that would otherwise be difficult or costly to gather for hired personnel (Kim et al., 2011).

Use of Citizen Science in Water Monitoring

One of the largest citizen science activities in the United States, in regard to the number of programs, is water quality monitoring (Grudens-Schuck & Sirajuddin, 2019). Historically, interest in volunteer water monitoring developed through a combination of environmental concerns that were prompted by increasing news coverage, changes in policy and law, changes in government budgets, increasing technology, and a shift in societal views throughout the 1970s (Stepenuck & Genskow, 2017). During this time, several new federal acts and policies focused on wildlife and the environment (e.g., Clean Air Act in 1970 and Clean Water Act in 1972). Data collection methods and expectations changed as a result of these new laws and acts, and citizen participation was encouraged as a means to contribute to the natural sciences. Many early volunteer environmental programs within the United States were focused on monitoring water, with a total of 760 active programs reported by 1998 (Stepenuck & Genskow, 2017).

The Clean Water Act (1972) required that states and tribes be responsible for reporting impaired waters annually and develop plans for reducing pollution of impaired water bodies. As a part of the act, states and tribes must consider all available water monitoring data for these water bodies, regardless of who collected the data (Stepenuck & Genskow, 2017). The Clean Water Act allowed for the use of citizen science data to be considered in the process of governmental decision-making. The Environmental Protection Agency (EPA) has pushed for state agencies to expand their monitoring efforts on water bodies and give increased reports to Congress, yet many agencies experience problems with understaffing, as well as budget and time restraints. Combined with the ability of agencies to use citizen collected data, as per the Clean Water Act, volunteer water quality monitoring programs have helped to provide a recognizable value to society (Alender, 2016). Kolok et al. (2011) suggest that local civic engagement in environmental monitoring, especially aquatic, provides citizens with information and education that ultimately may lead to corrective feedback actions undertaken by the general public. Citizen science programs go beyond simple data collection. These programs are effective not only in acquiring vast amounts of useful information, but in engaging and educating members of the public in watershed conservation issues.

As government agency budgets have decreased in recent years, and environmental concerns have increased, there has been a further need for citizen involvement in natural resource management and decision-making (Conrad & Hilchey, 2011). Many volunteer monitoring efforts now aid or supplement natural resource agencies in collecting required data used for annual reports, publications, and policy-decisions (Stepenuck & Genskow, 2017). The number of citizen science programs that focus on water quality ranged from 1,675 to 1,720 from 2013 to 2019, doubling the results collected from the 1990s (Grudens-Schuck & Sirajuddin, 2019; Stepenuck, 2013). An estimated 103,763 volunteers participated in 2017 doing water-related citizen science projects (Stepenuck & Genskow, 2017). At least twenty-six states sponsor volunteer monitoring programs (Overdevest, Orr, & Stepenuck, 2004) with many of these programs using data collected from volunteers to publish reports on water bodies that have the potential to be used for policy and resource management decisions (Metzenbaum, 2002). Citizen scientists help to collect water quality data across large spatial and temporal ranges which may be otherwise unfeasible to achieve.

Context of the Study

In Oklahoma, Blue Thumb is a state-sponsored citizen science program that focuses on water quality monitoring. Blue Thumb began as a collaboration between Oklahoma State University (OSU) Extension and the Tulsa County Conservation District in 1992 and later expanded statewide. Blue Thumb is now the education arm of the Water Quality Division of the Oklahoma Conservation Commission (OCC). The Blue Thumb program is the primary means by which the OCC addresses the Non-Point Source Pollution Management Plan (NPSMP) objective focused on education (Blue Thumb, 2019). The Environmental Protection Agency (EPA) funds Blue Thumb's activities through the 319-grant program. EPA expects that all states receiving these monies review and revise their nonpoint source pollution management plan every five years to continue receiving funding (EPA, 2012). Within their documentation, state programs must contain “explicit short- and long-term goals, objectives, and strategies to restore and protect surface water and groundwater” and “strengthen its working partnerships [...] to [...] citizens groups" among other environmentally specific goals (EPA, 2012). To this end, Blue Thumb publishes yearly reports to address specific short-term and long-term goals, as well as progress on designated subtasks that are assigned to the organization.

Blue Thumb trains volunteers to perform monthly monitoring of creeks and streams, with their data being used by the Oklahoma Conservation Commission. Some of Blue Thumb’s volunteers focus specifically on educational events and travel to many major cities in the state to host activities to raise awareness about water quality and conservation. In one-year, Blue Thumb reached over 19,000 people through education and outreach events in 42 counties of Oklahoma (Blue Thumb, 2019). The goal of Blue Thumb is “protection through education,” and this program aims to empower citizens in Oklahoma to not only monitor water bodies, but to become conservation leaders in the state. With more than 80 streams being monitored, over 300 active volunteers, and over 8,000 hours of volunteer time logged in one-year, Blue Thumb remains intensively engaged with Oklahoma citizens.

Within the citizen science typology created by Bonney et al., 2009a, Blue Thumb may best be identified as a “collaborative” project. Blue Thumb program administrators develop the specific research questions and hypotheses that the program is based on, but participants are welcome and encouraged to participate in research, reporting, and outreach. Participants may create their own questions, design their own methodology using existing Blue Thumb resources, and even conduct their own mini studies which Blue Thumb staff support. Participants also produce annual data reports for monitored streams, attend quality assurance meetings, and promote the use of Blue Thumb data across several learning communities such as schools or public events. Blue Thumb serves as a model of an active water monitoring citizen science program with aspirations for promoting educational outcomes across the state.

Blue Thumb offers many education/outreach opportunities for volunteers to engage in beyond the main stream monitoring program. Some of the main educational programs and activities include creek clean up events, fish printing for children, mini-academy (a short educational stream training aimed for educators or use in the classroom), a 3d watershed model ("enviroscape"), incredible journey – a lesson on the water cycle, creek walks, a stream trailer for mobile monitoring, and a tabletop rainfall simulator. Another program provided by Blue Thumb is groundwater monitoring, where screenings are performed for several water quality parameters with the goal of educating landowners. Volunteers are encouraged to engage at whichever level they feel most comfortable with, whether solely educational activities or dedicated monthly stream monitoring.

Blue Thumb annual evaluations to date have focused on programmatic successes rather than specific participant outcomes. Volunteers are assessed bi-annually with a quality assurance test, but are not evaluated currently for any specific science learning outcomes. Besides reporting program level tasks and requirements, Blue Thumb also reports measures of successes regarding volunteer recruitment and retention. While programmatic evaluations are necessary, and Blue Thumb is required to report these for continued funding, evaluating the outcomes of the individual participant experience is also important for the continuation of the program. Establishing evaluations that focus on participant outcomes would provide Blue Thumb with information that could be used to better shape program training, data collection, and volunteer recruitment and retention. This approach reflects individuals' stories and perspectives at a participant level, rather than solely a programmatic one.

Theoretical Framework

Within the realm of citizen science evaluation, recent studies have turned focus from trying to demonstrate increases in specific content knowledge to trying to understand what learning may be intended in a particular program, where it is happening, and the ways in which it is accomplished (Jordan, Ballard, & Phillips, 2012; Merlender et al., 2016; Phillips, 2017; Hecker, Garbe, & Bonn, 2019). It is important to understand the full participant experience in order to understand how and why desired learning outcomes are or are not met. The difficulty in studying where and how learning takes place in citizen science may, in part, be due to the highly interdisciplinary nature of citizen science which has many branches in education, environmental science, informal learning, psychology, and sociology (Phillips, 2017). Recent papers point out that many evaluations lack an established theoretical framework and defined categories of learning outcomes (Bonney et al., 2009b; Phillips, 2017).

This study applies Experiential Learning Theory (ELT) as an overarching framework helps us to better understand how active learning and scientific inquiry happen in place-based and data-rich volunteer programs. Experiential education has been applied as a framework to study many engaged learning contexts related to citizen science (i.e., field study, outdoor education, and civic engagement) (Carver, R., 1996; Blyler, K., 2014; Roche et al., 2020; Kloetzer et al., 2021). Experiential Learning Theory (ELT), developed by David A. Kolb (1984), has been called active learning due to the involvement of the participant in their learning experience. Rather than perceiving learning as a specific outcome, experiential learning theory views learning as a process, where new ideas and concepts are formed and reformed through learner experience (Kolb 1984; Stock, Kolb, & Kolb, 2021). Intuitively, the act of participating in citizen science programs involves the act of "learning by doing". Aligning volunteers' experiences to these processes of science inquiry helps us to understand when and how active learning occurs across the Blue Thumb programs and activities (Figure 1) (Olson & Colston, 2020).

Blue Thumb offers a range of informal science learning (ISL) experiences for youth and public audiences that range from passive learning (e.g., videos and exhibit) to active learning (e.g., games and hands-on demos) (Figure 1). Additionally, Blue Thumb engages formal learning contexts through teacher professional development and student mini academies. In terms of citizen science programming, Blue Thumb volunteers are primarily stream monitors who in their first year experience the complete Kolb Cycle by attending trainings, conducting stream monitoring, completing quality assurance testing, and annual reporting of stream quality. This evaluation specifically focuses on volunteers engaged in stream monitoring at these identified stages of active learning and science inquiry.

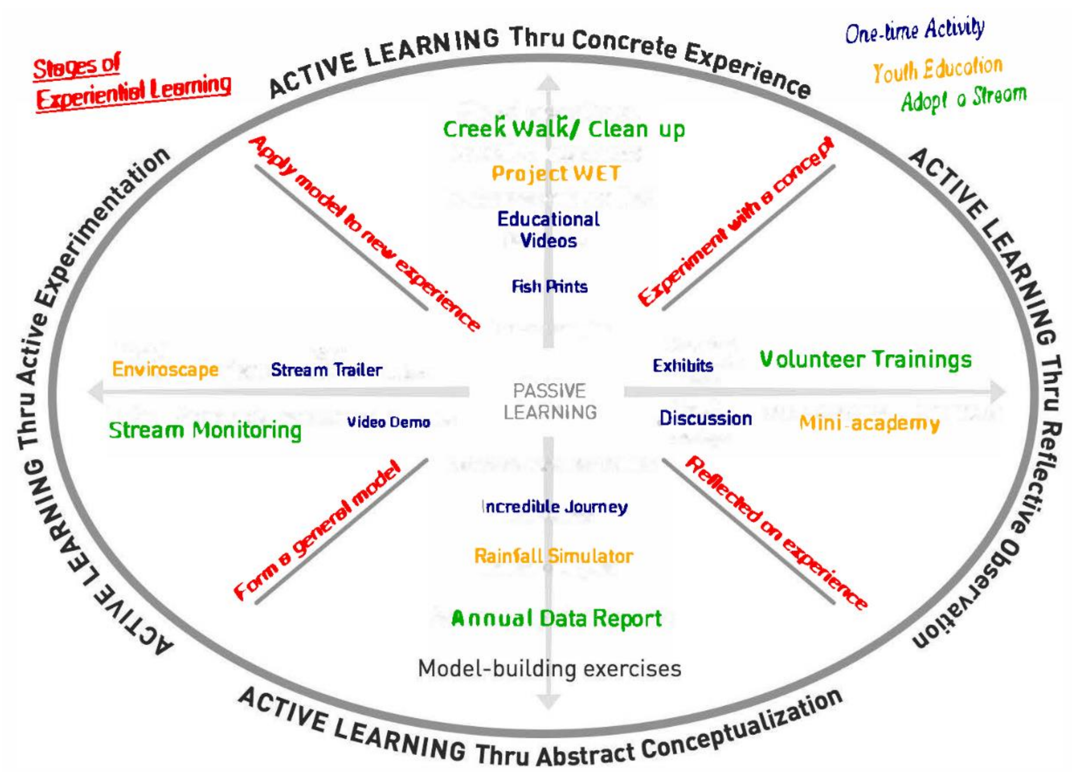

Figure 1: Conceptualizing science inquiry as stages of active learning highlighted keys points of volunteer engagement in stream monitoring: training, monitoring, reporting, and data assurance.

Study Purpose and Relevance

The purpose of this mixed methods research is to better understand how volunteer experience in place-based and data-rich programs influences their science learning, motivations, and data quality. A secondary goal of this study is to work with Blue Thumb to develop evaluation tools that may be used for program administration and annual reporting. This study applies a common learning outcomes framework (Phillips et al., 2018) for citizen science program evaluation, as well as adapts and validates developed instruments for behavior and stewardship, interest, motivation, skills, and self-efficacy (Bonney et al., 2009a; Phillips et al., 2018). This type of evaluation is needed, as previous evaluations in the field of citizen science have often lacked common frameworks and depended upon newly created and unvalidated instruments. For practitioners and program administrators, a common framework and valid instruments would make the process of evaluating programs simpler and may help to provide generalized information on the participant outcomes of citizen science broadly.

This study addressed existing gaps in the literature about appropriate volunteer outcome evaluation methodology, the connection between place-based attachments and volunteer motivations in environmental monitoring, and volunteer perceptions of data quality. By using mixed methodology, we can gain a deeper understanding of the level of evaluation needed to fully capture the experiences and outcomes of participants in citizen science research. Mixed methods have been increasingly incorporated into program evaluations since the early 1980s (Connor, Altman, & Jackson, 1984). Mixed methods evaluations allow the researcher to gain multiple perspectives and data to support their findings. By combining qualitative and quantitative data, the researcher is better able to support the development, adaptation, and evaluation of a specific program (Creswell & Plano Clark, 2007). This study has multiple phases, making this a more complex evaluation design.

Research Questions and Study Design

In preparation for this research, a survey and focus group were conducted with Blue Thumb staff to determine the course of program evaluation (Olson & Colston, 2020). Results of the survey and focus group indicated that Blue Thumb has a strong desire to examine three main learning outcomes: behavior and stewardship, interest, and motivation. Priority focus is placed on the three most desired outcomes identified by Blue Thumb, however additional learning outcomes from the Phillips framework are also assessed, including: self-efficacy and skills (Phillips et. al., 2018). Additionally, focus group discussions with Blue Thumb staff about programmatic activities and goals were used to generate and guide the research questions of this study. This study employs a mixed methods multiphase evaluation design to answer the following research questions:

1) To what extent and in what ways does length of participation impact volunteers' behaviors, motivations, and interests related to water quality monitoring?

2) How does place-based volunteerism influence differences in participation, motivations, and experiences?

3) What are volunteers' perceptions of self-efficacy and scientific skills and how do these outcomes relate to data quality?

This mixed methods evaluation of Blue Thumb consists of three distinct phases that will be identified and described below. Each phase of the evaluation utilizes different sampling strategies, methodologies, participant sample size, and procedures (Figure 2). The overall objective of all three phases is to evaluate the impact of participation in Blue Thumb on specific learning outcomes, and to capture the perceptions and motivations of the various volunteers within this program. These phases are: 1) survey assessment of the impact that participation in Blue Thumb has on individual learning outcomes, such as behavior and stewardship, interest, and motivation, 2) interviews to relate motivation for volunteerism to place-based attachments and 3) a mixed methods analysis relating data quality to participant perception of skill and self-efficacy. The quantitative data include a series of modified surveys designed by Cornell Lab of Ornithology to test learning outcomes (Appendix A, D), newly generated surveys designed in collaboration with Blue Thumb staff, and a final quality assurance test (Appendix C) to compare participant data against a known value. Qualitative data consist of open-ended survey questions on the participant survey related to each learning outcome, and interviews with select participants to assess how their experiences influence learning outcomes, as well as perceptions of their skill and self-efficacy in data collection. The justification for using a mixed methods approach is to transcend the traditional quantitative pre-post assessment of participant outcomes that are commonly used in citizen science evaluation. Qualitative data is necessary in the context of this study to provide explanatory analysis of quantitative data.

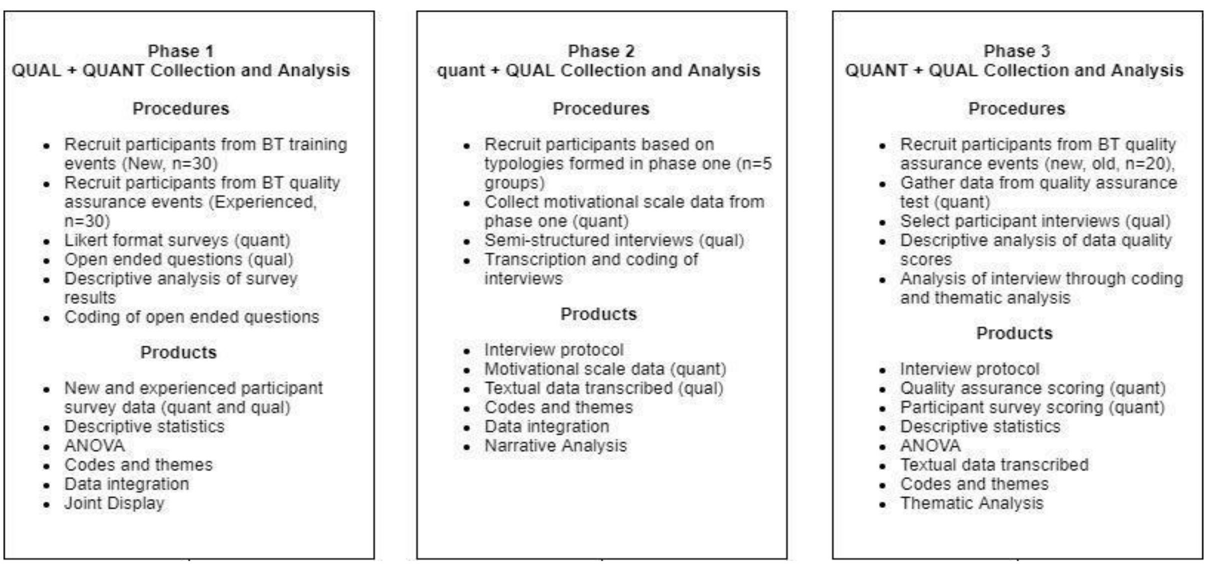

Figure 2: A procedural diagram of the multiphase evaluation mixed methods design utilized in this study. Each distinct phase is analyzed independently, then combined in a final integration phase.

This dissertation uses an article-style format, with a total of five chapters. Chapter one serves as an introduction and literature review. Chapters two through four each are individual articles written over sequential phases of the research. Chapter five contains a conclusion chapter to summarize the major findings of all three articles. Below, there are descriptions of chapters two through four.

To address gaps in our knowledge about evaluating citizen science participant outcomes, Chapter 2 seeks to answer to what extent and in what ways does length of participation impact volunteers' behaviors, motivations, and interests related to water quality monitoring? This article uses a convergent mixed methods design that consists of a quantitative survey of participants with qualitative open-ended questions (Appendix A). Surveys were modified versions of participant outcomes surveys created by Cornell Lab of Ornithology, as they have been previously tested for validity and used in other evaluation publications (Flagg et. al., 2016; Phillips et. al., 2017a; Porticella et. al., 2017a; Porticella et. al., 2017b). These modified surveys include the General Environmental Stewardship Scale (GESS), Interest in Science and Nature Scale (ISNS), Motivation for Environmental Action Scale (MEAS), and Motivation for Doing and Learning Science Scale (MDLSS).

In order to explore the importance of place attachment in stream monitoring, Chapter 3 asks how does place-based volunteerism influence differences in participation, motivations, and experiences? This research consisted of semi-structured qualitative interviews (Appendix B) with a convenience sample of volunteers in Blue Thumb, ranging from landowners to students to researchers. Narrative analysis focused on capturing examples of three major types of place-based attachments.

Given concerns over data quality and volunteer training, Chapter 4 asks what are volunteers' perceptions of self-efficacy and scientific skills and how do these outcomes relate to data quality? A mixed methods sequential design analyzes participants' perceptions of self-efficacy and scientific skills and how these outcomes relate to data quality. Participants collected water quality parameter data (Appendix C), completed a compiled self-efficacy survey (Appendix D), and then followed up with semi-structured interviews (Appendix E) to investigate their perceptions of their self-efficacy at quality assurance events. Analyses included descriptive statistical analysis of collected water quality parameter data to compare volunteer accuracy when sampling. Self-efficacy scores, and qualitative responses, were compared to data accuracy reflections from quality assurance testing to investigate any potential relationship (Linneberg & Korsgaard, 2019).

Conclusion

Many citizen science programs, including Blue Thumb, rely on annual funding from grants and other financial resources to further develop and promote their programs. Often, these financial sources require citizen science programs to demonstrate quantitatively and/or qualitatively that several criteria such as specific participant outcomes have been successfully met. The EPA 319 Funding Program that Blue Thumb benefits from outlines specifically that each funded state program must contain explicit short- and long-term goals, objectives, and strategies that indicate measures of success (Environmental Protection Agency, 2012). This research will help to identify gaps in our current understanding of individual learning outcomes, and further examine the role that place-based volunteerism has on several distinct markers of success for Blue Thumb evaluation. Results from this study will be used to inform the field of citizen science about potential barriers to volunteer behaviors, motivations, interests, and the collection of high-quality data in environmental monitoring programs. By using established frameworks for evaluation of specific citizen science outcomes, this work further supports improving existing methodologies for overall program evaluation. Finally, and importantly, this work is intended to be used by Blue Thumb program administrators to help improve future volunteer recruitment, engagement, and retention efforts.

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CHAPTER II

EVALUATING CITIZEN SCIENCE: MOVING BEYOND OUTPUT MEASURES TO LEARNER BEHAVIORS, INTERESTS, AND MOTIVATIONS

Introduction

Citizen science has gained momentum in recent years and involved members of the public in ongoing scientific research. Citizen science is often defined as a form of research collaboration that engages citizens, who are non-professional scientists, in scientific research projects that involve data collection, analysis, and dissemination (Conrad & Hilchey, 2011; Crowston and Wiggins, 2011; Dickinson et. al., 2012a; Haklay, 2013). The evaluation of these programs is an emerging area of study. Engaging the public in scientific research has several potential societal and individualized benefits. Citizen science projects provide educational experiences that could potentially enhance participants' knowledge about a species or topic, heighten participant awareness to a topic, and increase scientific literacy (Bonney et al., 2009; Briggs, Stedman, Krasny, & Krasny, 2014). By participating in scientific research and working collaboratively, citizen science projects often aim to increase learning outcomes within the population of volunteers who participate in such programs.

While citizen science projects have been successful in advancing scientific knowledge and achieving specific research or program outcomes, more focus is now being placed on evaluating the impacts of citizen science on the participants involved (Eyler et al., 2009; Phillips et al., 2018). Previous research has predominantly focused on measuring engagement in citizen science through output measures, such as the number of participants or the amount of data collected (Phillips et al., 2018). A new focus is being given to evaluating the learning outcomes of participants. In particular, the field of citizen science has begun to ask questions such as "who are the volunteers?", "what are the outcomes of participation?", and "in what ways does volunteer experience shape desired outcomes?"

In Oklahoma, Blue Thumb is a state-sponsored citizen science program that focuses on water quality monitoring. Blue Thumb is the educational arm of the Water Quality Division of the Oklahoma Conservation Commission. The Blue Thumb program is the primary means by which the Oklahoma Conservation Commission addresses the Non-Point Source Pollution Management Plan (NPSMP) objective focused on education (Blue Thumb, 2019). Blue Thumb trains volunteers to perform monthly monitoring of creeks and streams. The goal of Blue Thumb is "protection through education": this program aims to empower citizens in Oklahoma to not only monitor water bodies, but to become conservation leaders in the state. With more than 80 streams being monitored, over 300 active volunteers, and over 8,000 hours of volunteer time logged in one-year, Blue Thumb remains intensively engaged with Oklahoma citizens. Blue Thumb serves as a model of an active water monitoring citizen science program with aspirations for promoting educational outcomes across the state.

Blue Thumb annual reports to date have focused on programmatic successes rather than specific participant outcomes. Besides reporting program level tasks and requirements, Blue

Thumb also reports measures of successes regarding volunteer recruitment and retention, such as: the number of new volunteers that completed training events each year, any volunteer participation in educational events, the number of volunteers who participate in monthly monitoring and the frequency of the data they have collected, and more. While programmatic evaluations are necessary, and Blue Thumb is required to report these for continued funding, evaluating the outcomes of the individual participant experience is also important for the continuation of the program. Establishing evaluations that focus on participant outcomes would provide Blue Thumb with information that could be used to better shape program training, data collection, and volunteer recruitment and retention. Within this study, Blue Thumb program administrators were interested in knowing how participation in Blue Thumb influence pro-environmental behaviors, what are the initial driving interests and motivations of Blue Thumb volunteers, and how does participation in Blue Thumb change those interests or motivations over time.

Evaluation of outcomes from participation in citizen science is often listed as a “high priority” for practitioners and program coordinators, yet it is commonly rated to also be one of the largest challenges. Published evaluations of participant outcomes in individual citizen science projects are limited in quantity. While research or program outcomes are often evaluated for reporting purposes and to justify the continuing programs, evaluations of individual or social outcomes are much less common. There are few established indicators or methodologies for evaluating citizen science and there exists an overall lack of consistent definitions and desired categories of participant outcomes. Most published evaluations rely on pre- and post-test self-reported measures. This research applied a common evaluative framework to measure how participation in Blue Thumb influenced volunteers’ environmental behaviors, scientific interests, and motivations for volunteerism.

Evaluation of Participant Outcomes

Despite the general agreement on the importance of evaluation, the field struggles with theoretical, technical, and even practical aspects of measuring learning and participant impacts (Eyler et al., 2009). Many citizen science projects have lacked evaluation, have conducted less than rigorous evaluations, or conduct evaluations that do not use available theories, frameworks, or tools. A recent study of citizen science projects globally suggests that only about 50% of citizen science project leaders have evaluated their individual projects, and that only a small number of these evaluations have systematically assessed broader cognitive, affective, and behavioral outcomes linked to participant engagement (Bonney et al., 2014; Phillips et al., 2018). Inconsistent or lacking evaluations pose a problem for the field of citizen science, as evaluations serve to help better understand the effectiveness of such programs and the reach they may have.

In most published evaluations, pre and post-test survey techniques are a common method to assess participant outcomes in environmental monitoring (Brossard, Lewenstein, & Bonney, 2005). A recent literature review of biodiversity projects by Peter et al. (2019) found that a majority of projects use post-only design, with pre and post-test surveys as a second common method, and no comparative studies with control groups. The most frequently used instrument was a questionnaire, while the least frequently used instrument was participant reflections. Many projects analyzed data quantitatively rather than qualitatively. In addition, only a few of the studies based their research on previously established frameworks. Of the papers concerned with water citizen science program studies, all but one of the programs used surveys as the medium for evaluation (Peter et al., 2019). Nearly all the studies captured in the review by Peter et al. (2019) used a Likert scale with a pre-post, or simply post, test design. There exists a need for diversification in methodology of evaluations that go beyond quantitative pre- and post-tests to truly capture participant outcomes across various projects in the field of citizen science.

In the study of informal science education (ISE) and citizen science, there have been few notable articles which have attempted to place participant outcomes into quantifiable categories. The most modern approach, "A Framework for Articulating and Measuring Individual Learning Outcomes from Participation in Citizen Science" (Phillips et al., 2018) re-conceptualized several categories noted across previous articles related to informal science learning and several studies have taken these concepts and applied them to a citizen science perspective. These categories include content, process, and nature of science knowledge, interest in science and the environment, skills, self-efficacy for science and the environment, behavior and stewardship, and motivation.

Using the Phillips et al. (2018) framework, Blue Thumb was given a needs assessment survey that asked staff to rate each major activity or program by a) time involvement/level of engagement for the participants, and b) which learning outcomes were best captured or intended (Olson & Colston, 2020). The results were used to identify three major learning outcomes Blue Thumb desired to evaluate: behaviors and stewardship, motivation, and interest. Previous work by Eyler et al. (2009) suggests that citizen science programs should not attempt to evaluate all listed outcomes, and instead focus on evaluation that pertains to each program's main desired outcomes. A definition of each major learning outcome evaluated in this study, and related evaluation tools provided by Cornell Lab of Ornithology Developing, Validating, and Implementing Situated Evaluation Instruments Project (DEVISE) (https://www.birds.cornell.edu/citizenscience/measuring-outcomes/) , is presented below (Table

1). Then follows a literature review of which methodologies have been used for previous evaluation of these outcomes.

Table 1: Description of Phillips et al., 2018, definitions for three major learning outcomes with links to survey items. BT = Blue Thumb.

Construct	**Definitions and Blue Thumb Examples**	**DEVISE Scales**
Behavior and Stewardship	Measurable behaviors that result from engagement in citizen science projects but are external to protocol or skills of the specific citizen science project. BT examples: - Water conservation behaviors - Yard maintenance and gardening - Reduction of water-related pollutants such as pesticides or herbicides	General Environmental Stewardship Scale
Interest in Science and Nature	The degree to which an individual assigns personal relevance in a topic or endeavor, and their actions taken towards pursuing that endeavor. BT examples: - Involvement in different BT programs - Level of engagement in stream monitoring	Interest in Science and Nature Scale
Motivation for Participation in Citizen Science Motivation for Doing and Learning Science	Factors that activate, direct, and sustain goal-directed behaviors' ' and are the "whys" that explain what drives participation. BT examples: - Reasons for original recruitment and continued participation - Reasons for engagement in specific projects	Motivation for Participation in Citizen Science Scale Motivation for Doing and Learning Science Scale

Behavior and Stewardship

Behavior change/environmental stewardship is often considered to be the "most sought-after outcome" for environmental citizen science programs, as seen in surveys of biodiversity projects (Peter et al., 2009; Phillips et al., 2018). Environmental citizen science projects usually involve repeated hands-on experiences in nature and provide opportunities for the development of specific behavior changes (Phillips et al., 2018; Wells & Lekies, 2012) such as positive attitudes towards the environment that are linked to pro-environmental behaviors (Brossard, Lewenstein, & Bonney, 2005; Heimlich & Ardoin, 2008; Merenlender et al., 2016) and involvement in policy making (Jordan et al., 2011). Blue Thumb administrators describe specific desired behavior changes but have no formal assessment of volunteers (Table 1, Olson & Colston, 2020). Although projects vary and frequently have certain behaviors linked with participation, there is no one universal method for monitoring behavioral outcomes in citizen science. There are scales for measuring environmental stewardship in general and ecologically favorable actions like recycling (Phillips et al., 2017), however many citizen science initiatives develop their own questionnaires to assess the desired project-specific behaviors.

Interest in Science and the Environment

A "key driver" of pursuing science jobs, sustaining lifelong involvement, creating a science identity, and laying the groundwork for more intensive engagement techniques like environmental stewardship is an individual's interest in science (Falk, Storksdieck, & Dierking, 2007; Maltese & Tai, 2010; Phillips et al., 2018). According to studies, interest is a component that affects involvement levels and helps to keep highly active volunteers on board (De Moor et a., 2019; Nov, Arazy, and Anderson, 2014). Many challenges exist to capturing interest and engaging volunteers in a particular project. Problems such as the voluntary nature of citizen science, personal circumstance, lack of compensation, and competition with other priorities may influence engagement from volunteers (Geoghegan et al., 2016; Frensley et al., 2017; De Moor et al., 2019). While interest and engagement are desired outcomes, there is currently little information on how a citizen science project should measure them. In many cases, quantitative engagement measures (e.g., amount of time dedicated to an activity, number of activities participated in, number of submitted contributions over time) are used to reflect participant interest in a project (De Moor et al., 2019).

***Motivation for Science and the Environment*.**

Motivation is an attitudinal construct that describes a form of goal setting in order to achieve a specific behavior or desired result (Phillips et al., 2018). Studies on motivation in citizen science agree that motivation can change over time, multi-faceted, tied to volunteer retention and engagement in a particular project, and difficult to narrow down for evaluations (Alender et al., 2016; Hajibayova, 2020; Porticella et. al., 2017; Rotman et al., 2014; Raddick et al., 2010). One key theoretical framework used in citizen science literature to describe motivation is Self-Determination Theory (SDT), first described by Miller, Deci, and Ryan (1988). Self-determination theory places motivation on a scale from intrinsic motivators (i.e., satisfaction in behaviors participants perform on their own) to extrinsic motivators (i.e., rewards for participation or societal pressures) that can be used to describe "why" participants participate in citizen science projects (Porticella et. al., 2017). Few studies have attempted to evaluate motivation beyond trying to capture how to keep volunteers engaged, and fewer studies still have attempted to align SDT with citizen science learning outcomes (Ryan & Deci, 2000a, 2000b).

Study Purpose

The purpose of this mixed methods study is to evaluate how length of participation in a citizen science program influences learning outcomes behaviors, interests, and motivations of volunteers. This study attempts to answer the following research question: To what extent, and in what ways, does length of participation influence volunteers' behaviors, motivations, and interests as they relate to water quality monitoring?

Methods

Survey Design

This study utilized a convergent mixed methods design that consisted of a quantitative survey of participants with open-ended qualitative questions at the end (Appendix A). The survey items were intended to capture the identified participant outcomes determined during the previous focus groups with Blue Thumb Staff (i.e., behavior and stewardship, interest, and motivation). These surveys were modified versions of participant outcomes surveys created by Cornell Lab of Ornithology, in their DEVISE project, as they have been previously tested for validity and used in other evaluation publications (Chase et al., 2016; Phillips et. al., 2017b; Porticella et. al., 2017a; Porticella et. al., 2017b).

Surveys used in this research include: the General Environmental Stewardship Scale, or GESS, the Interest in Science and Nature Scale, or ISNS, the Motivation for Participation in Citizen Science Scale, or MPCS, and the Motivation for Doing and Learning Science Scale, or MDLSS. The GESS includes 6 different survey items, scored from 1-6 (1="I don't do this", 6="I can't imagine NOT doing this"), and produces a range of totaled responses from 0-36 where higher scores indicate higher levels of pro-environmental behaviors. The ISNS scores participants from 1-5 (1="strongly disagree", 5="strongly agree"), where scores closest to 5 indicate higher levels of interest in science. The MPCS and MDLSS scores were ranked from 1-5 (1="strongly disagree", 5="strongly agree"). An average of individual response was measured and used to determine overall motivational levels, where scores closest to 5 indicated higher levels of interest. Secondarily, motivations were also classified as either "intrinsic" or "extrinsic" on each scale according to the original survey items, and average responses for each type of motivation were calculated. Intrinsic responses were subtracted from extrinsic responses, as suggested by Phillips et al. (2017), to produce a "total response", where positive scores indicate predominately intrinsic motivations, and negative scores indicate predominately extrinsic motivations.

Modifications to each survey included changing terminology to be consistent with Blue Thumb subject matter and shortening of the number of survey questions to relevant content. In addition, the versions used in this study may be older than current editions available through the Cornell Lab of Ornithology Citizen Science portal. To ensure valid survey results, two measures were taken: one, participants could not submit a survey unless all scale item responses were answered, and secondly, each scale contained attention filler questions to ensure that participants read the survey carefully before responding.

Qualitative questions at the end of each survey item were designed to provide open-ended responses that probed participants further about each scale/learning outcome. These questions focused on what environmental behaviors each participant engages in, how training/monitoring has changed their interests, their driving motivations for originally signing up for a citizen science program, and what motivations or interests sustain their continued participation in Blue Thumb. Qualitative questions were intended to enhance meaning or give context to the previous quantitative survey results.

Sampling and Survey Distribution

Blue Thumb volunteers were divided into two categorical groups: “new volunteers” and “experienced volunteers” using criterion (purposeful) sampling methods (Palinkas et al., 2016). New volunteers were 18 years or older, new to the Blue Thumb program, had successfully completed a two-day training, and had not yet begun monitoring a stream. Experienced volunteers were 18 years or older, had successfully completed a two-day training, and had been active monitors at a stream site with at least three months of data entry.

Different survey distribution techniques were used for each volunteer sampling category. New volunteers were given the survey in-person, based on their availability at the completion of training events hosted by Blue Thumb. Experienced volunteers had two methods of completing a survey: a) a digital survey distributed through Qualtrics™ survey software (Qualtrics, 2020), or b) hard copies distributed at Blue Thumb quality assurance semi-annual events for those with limited computer access.

Data Analysis

Quantitative survey results were analyzed using SPSS software to produce descriptive statistics. A chi-squared test was performed to identify any potential differences between volunteer demographics based on level of experience. Significant differences in survey scores between new volunteers and experienced volunteers were analyzed with Mann-Whitney U tests, with post-hoc tests conducted subsequently. A linear regression was completed to examine the relationship between length of participation in experienced volunteers and learning outcomes. Qualitative data analysis was facilitated using QDA Miner software (“QDA Miner 4.0”, 2015). Structural coding was used identify and to generate statements that related to each of the intended learning outcomes (Church et al., 2019) by tagging qualitative responses with “behavior”, “interest”, or “motivation” tags. These tags were used to determine frequencies on the occurrence of specific words or phrases, based upon the number of responding participants.

The last step of data analysis involved integration of quantitative and qualitative data. Integration involves combining both types of data to develop results and interpretations that expand on the total understanding of results and provide more comprehensive information

(Creswell et al., 2011). During integration, focus was placed on how qualitative findings explained participant survey scores for behavior, interest, and motivation. Both types of data were then analyzed in a side-by-side comparison.

Results

Demographic Summary

The full dataset contained new volunteer (n = 41) and experienced volunteer responses (n = 33), for a total of 74 participants (Table 2). However, not all participants answered every question; thus, sample sizes vary among demographic parameters (Table 3). Demographically, new volunteers were younger and still in college whereas experienced volunteers were older and had already completed college (Table 2-3). No difference in gender was noted between experience level, with approximately two-thirds of volunteers identifying as female. Overall, Blue Thumb volunteers are a highly educated group with existing science training. A chi square test of independence showed no significant association between experience level and demographic data (Table 3).

Table 2: Demographic data between new (N=41) and experienced volunteers (N=33).

Demographic	New	Experienced	Full Sample
Sex			
Female	26	22	48
Male	15	9	24
Nonbinary	0	2	2
Age			
>=24	19	8	27
25 to 39	12	8	20

40 to 60	3	5	8
60+	4	7	11
Education			
K-12	2	0	2
High School	1	0	1
Some College	11	2	13
Associates	3	5	8
Bachelors	12	10	22
Masters	8	9	17
Doctorate	3	6	9
Career			
College Professor	1	5	6
College Student	17	10	27
Government Employee	0	6	6
Group/Other	3	2	5
Hobbyist	1	0	1
K-12 Student	3	0	3
K-12 Teacher	1	2	3
Landowner	4	3	7
Scientist	8	5	13

Table 3: Chi-square test between new and experienced volunteer demographics.

Demographic	**N**	**df**	**Value**	**Significance**
Gender	74	2	3.04	0.22
Age	66	35	34.03	0.52
Education	72	2	10.21	0.17
Career	71	7	13.61	0.06

New vs Experienced Volunteer Scores

To assess the impact of length of participation from the Likert scale data, Mann-Whitney U tests were conducted in SPSS to compare survey results for desired outcomes (behavior, interest, and motivation) between new (level "N") and experienced (level "E") volunteer groups (Table 4). Motivation for Participation in Citizen Science was significantly higher for experienced volunteers compared to new volunteers (p = 0.03). There were no statistically significant differences between new and experienced volunteers for behavior and stewardship, interest in science, and motivation for doing/learning science.

Table 4: Comparison of all survey item total response scores between new and experienced volunteers with a Mann-Whitney U test. N = new and E = experienced volunteers. Scores can range from 0-36, where scores closer to 36 indicate a higher individual stewardship index.

Outcome	Level	n	Average	Std. Deviation	Z	p-value
Behavior and Stewardship	N	41	28.3	0.93	-1.66	0.10
	E	33	31.58	1.26		
	All	74	29.77	1.10		
Interest in Science	N	41	4.09	1.40	-0.06	0.96
	E	33	4.66	0.59		
	All	74	4.41	1.00		
Motivation for Citizen Science	N	41	0.61	0.63	-1.99	0.03
	E	33	0.95	0.68		

	All	74	0.78	0.66		
Motivation for Doing/Learning Science	N	41	1.50	0.90	-0.10	0.92
	E	33	1.55	0.85		
	All	74	1.53	0.88		

Behavior and Stewardship

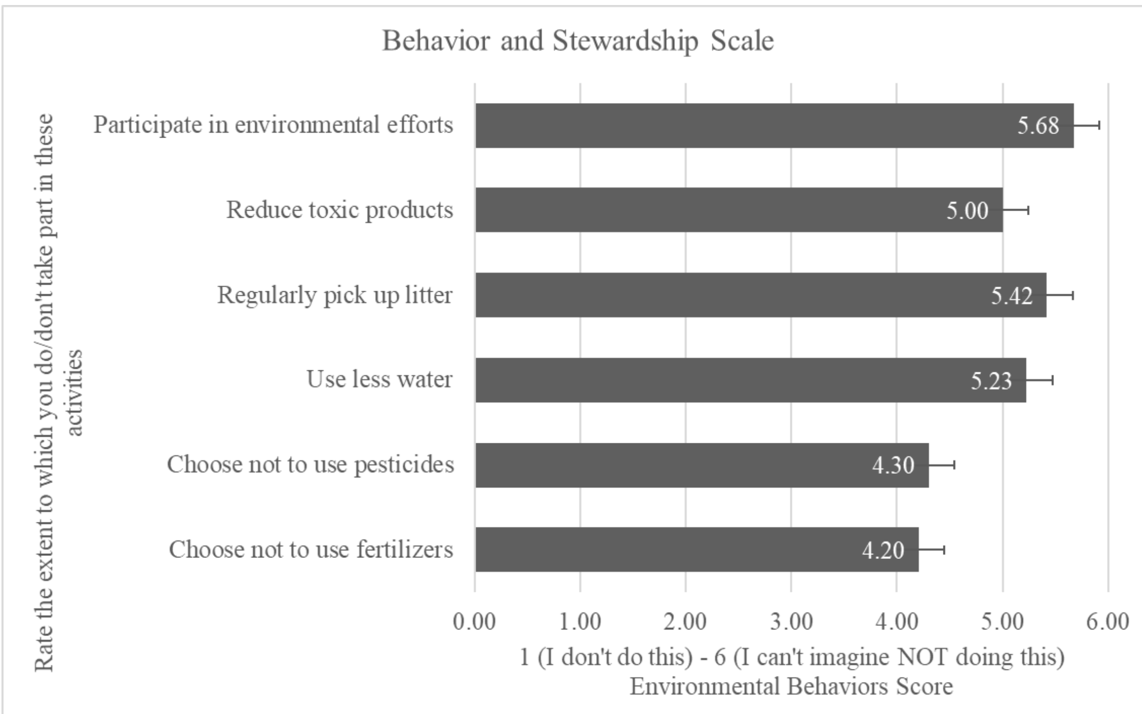

Figure 3: General Environmental Stewardship Scale survey items response scores.

On the Behavior and Stewardship Scale, volunteers averaged a total behavioral score of 29.77 out of 36 possible points (Table 4) indicating high levels of pro-environmental behaviors. On the survey item, volunteers reported that they were currently engaged (averages above a score of 4, “I am currently doing this”) in all the listed pro-environmental actions (Figure 3). Scores were higher for volunteer participation in environmental efforts, using less water, and regularly picking up litter. Qualitative responses included additional categories of environmental behaviors such as sustainable shopping, energy use, alternative transportation, plastic reduction, composting, stream clean ups, and dietary changes (Table 5).

Table 5: Open-ended pro-environmental behavior items response code frequencies.

Behaviors	**Total Responses**	**%**
Recycling	35	47%
Gardening	18	24%
Sustainable Shopping	11	19%
Energy Use	10	15%
Alternate Transportation	10	14%
Plastic Reduction	9	14%
Composting	7	12%
Stream Clean Ups	6	9%
Dietary Changes	6	9%

Experienced volunteers were given an additional open-ended survey question that probed how, if at all, Blue Thumb had influenced the environmental actions and attitudes of experienced volunteers. Coding of responses generated two categories of answers: change in pro-environmental actions/ environmental attitude, or no increase/change in action or attitude (Table 6). A large majority of responses (75%) indicated a change in either attitude or behavior based on their participation. Many volunteers described how advocacy and education had become new and important behaviors for them, as with one volunteer who stated, “I strongly advocate for riparian areas and stream banks now (….) I am more apt to volunteer in environmental activities for education and encourage all of my family and friends to visit Blue Thumb's website". 56% of responses in this category reported participation in additional activities that ranged from educational presentations at regional conferences, virtual environmental webinars, and participation in other citizen science events such as BioBlitz, iNaturalist, and Project WET. 24% of responses reported no change in attitude or behavior since beginning Blue Thumb, with all responses in this category explaining previously established high levels of pro-environmental attitudes and behaviors that led them to joining Blue Thumb. As one volunteer reported, "I'm not sure my attitude has changed because I've always cared for the environment".

Table 6: Response code frequencies for changes in environmental attitudes and behaviors in experienced volunteers (n= 17 total responses).

Response	**n**	**%**	**Examples**
Change in environmental attitude or behavior	13	76%	Increased awareness and appreciation, advocation, behaviors specifically to protect water quality concerns, education and recruitment of others, participation in other environmental activities
No change	4	24%	High environmental attitudes and behaviors before joining, consistent level of environmental action

Interest in Science and the Environment

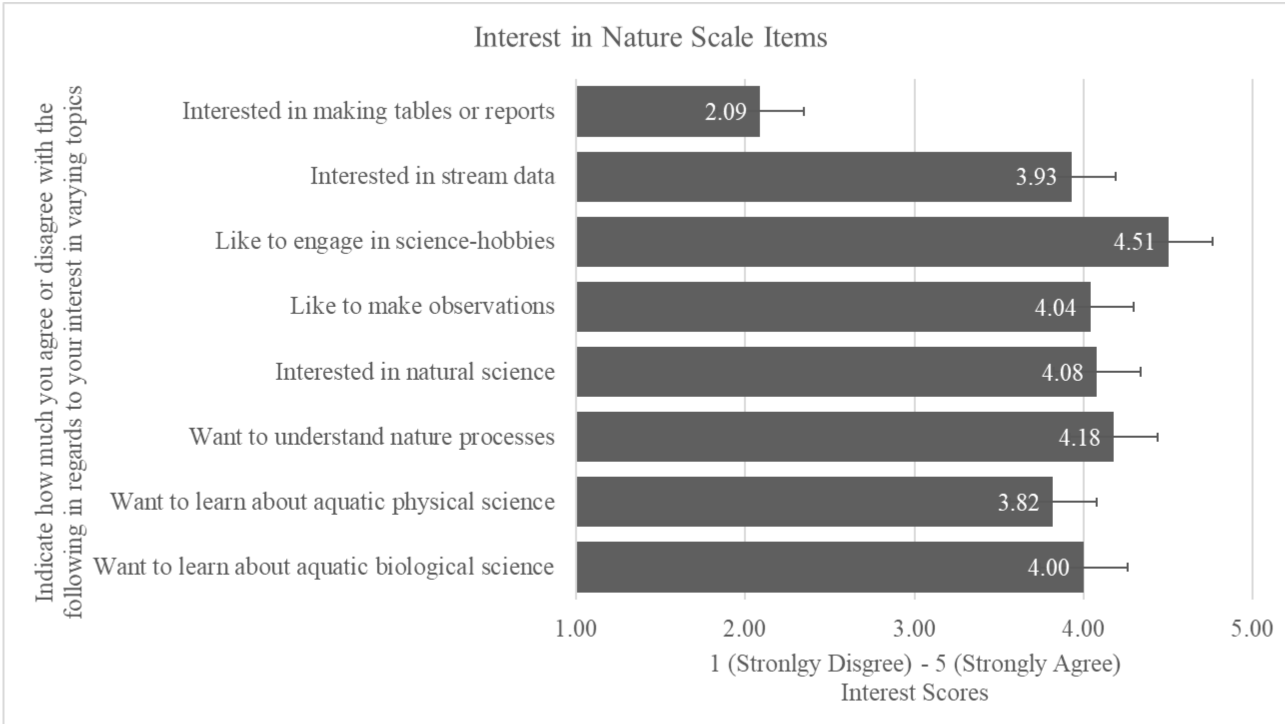

Figure 4: Interest in Nature Scale survey items response scores.

On the Interest in Nature Scale, volunteers averaged a response score of 4.41 (Table 4) indicating high levels of interest in nature and science. On the survey item, volunteers reported that they were interested (averages above a score of 4, “Agree”) in all the listed topics of interest excluding “making tables or reports” and “learning about aquatic physical science” (Figure 4). Volunteers were asked which aspects of stream-monitoring they were most interested in within an open-ended survey question (Table 7). The most reported interests included biological observations, macroinvertebrates and fish, chemistry, and being in nature.

Table 7: Open-ended interest items response code frequencies (n= 70 total responses).

Interest Topic	**Total Responses**	**%**
Macroinvertebrates	22.00	31%
Fish	21.00	30%

Chemistry: Chemical tests	17.00	24%
Being in nature	16.00	23%
Influences to water quality	15.00	21%
Data collection and interpretation	14.00	20%
Wildlife around stream	10.00	14%
Education	5.00	7%

Experienced volunteers were given an additional open-ended survey question that prompted them to answer how their interests in water monitoring, stream education, or participation had changed from when they first started, if they had changed at all (Table 8). Analysis of experienced volunteer responses led to the generation of three coding categories: increased interest, no change to interest, and barriers to interest.

Many experienced volunteers (55%) relayed that their perceived level of interest had increased over time, such as in the case of the participant quoted below, "I've mostly become more aware of what is available to learn and participate in with Blue Thumb and stream monitoring and that has made me more interested in participating or learning". In some cases, these were increases to specific interests (such as more interest in data interpretation and education of others), or increased interest in participation (more dedication to consistent, routine monitoring of a stream). Notable quotation included: "My interest, especially in educating others, has increased […] I am definitely more interested in stream education now than I was before". 24% of respondents reporting no overall change in interest, either indicating that they had high levels of pre-interest before joining Blue Thumb or that there was a consistent level of interest from when they had begun. One experienced volunteer said, "My interests have not changed significantly. I have always cared for every aspect of environmental science". Another volunteer agreed with the previous statement and added, “I am more aware, I think, but I don’t think my interests have changed significantly […] as I was always pretty interested”.

Experienced volunteers additionally indicated in qualitative responses that they were more aware of barriers or challenges that made it more difficult for them to explore their interests. The largest of these challenges was time: experienced volunteers felt that though they wanted to engage in topics beyond the required stream monitoring aspect of Blue Thumb, that they felt they did not have enough personal time to do so. One volunteer described their barriers to interest as follows, “I am sometimes overwhelmed by what I want and need to do, and how much time there really is […] I would like to be more involved beyond stream monitoring with Blue Thumb but have trouble finding the time”.

Table 8: Response code frequencies for changes in interest in experienced volunteers.

Response	**n**	**%**	**Examples**
Increased interest	18	55 %	Dedication, consistency in monitoring, environmentally conscious, more education, data interpretation
No change	8	24 %	Neutral (no change), pre-interest before joining, consistent level of interest
Barriers to interest	7	21 %	Lack of time, scheduling conflicts, desire for more involvement

Motivation for Citizen Science and Doing/Learning Science

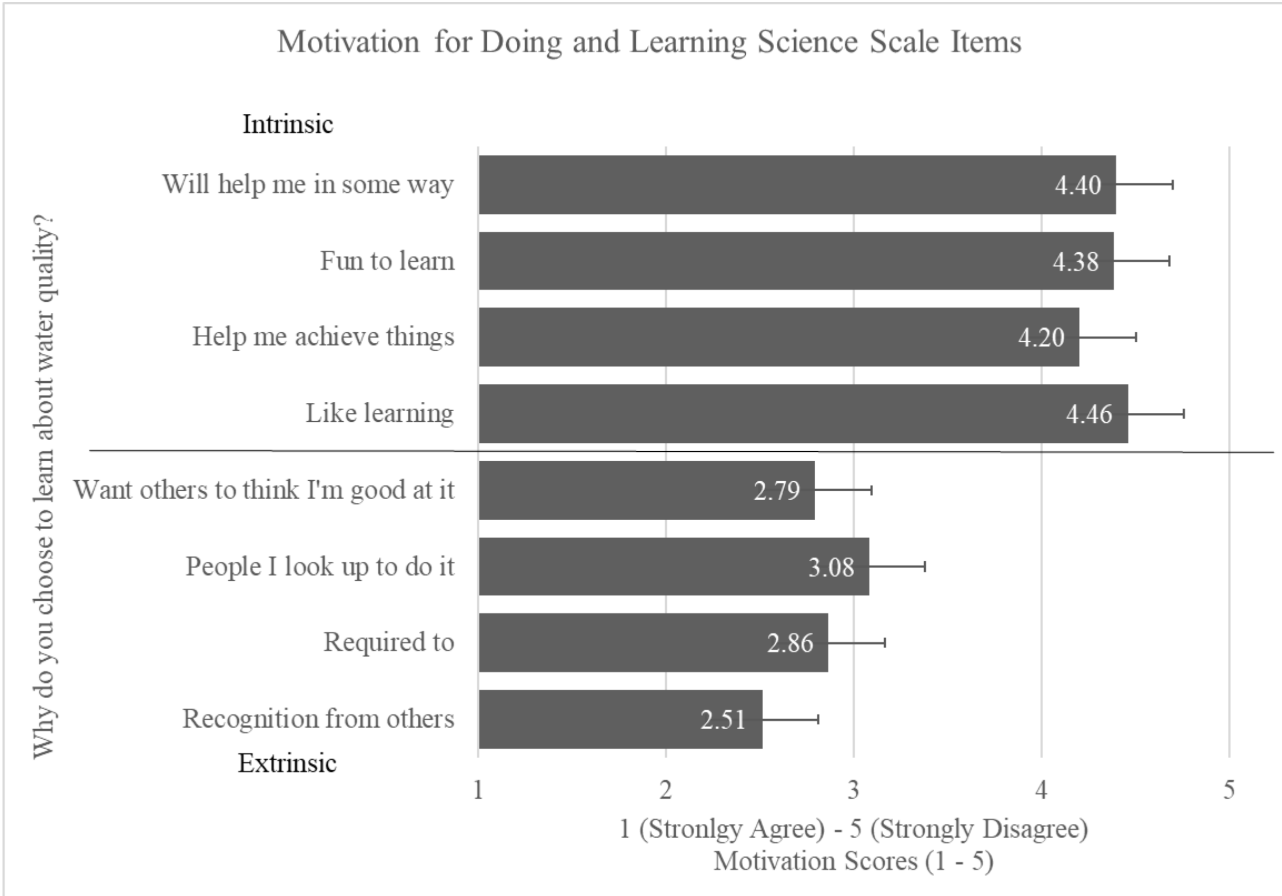

Figure 5*:* Motivation for Doing and Learning Science Scale survey items response scores.

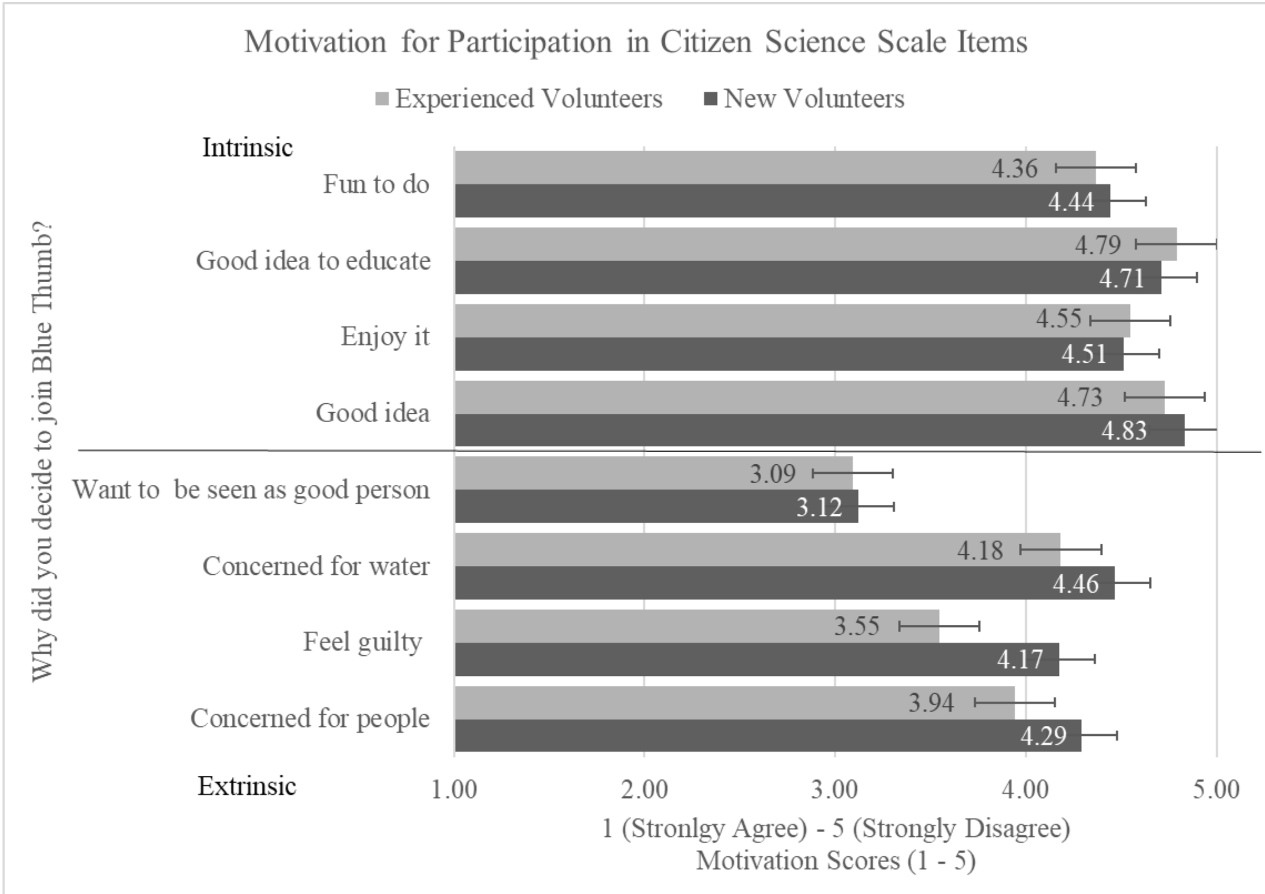

Figure 6: Comparison of Motivation for Participation in Citizen Science scale items response scores between new and experienced volunteers.

Two modified motivational scales were used: the Motivation for Participation in Citizen Science Scale (Phillips et al., 2017) and the Motivation for Doing and Learning Science Scale (Porticella et al., 2017). On the Motivation for Doing and Learning Science Scale, volunteers averaged a response score of 0.1.55, where positive scores indicate intrinsic motivations (Table 4). On the survey item, volunteer responses were above 4 ("I agree") for intrinsic items, and less than 4 for extrinsic items (Figure 5). Significant differences were found between new and experienced volunteers on the Motivation for Participation in Citizen Science Scale (Table 4). New volunteers averaged a response score of 0.61 while experienced volunteers averaged a response of 0.95, indicating higher levels of intrinsic motivation in experienced volunteers.

Responses to survey items varied most between new and experienced volunteers in extrinsic motivators (Figure 6). Differences to response on the Motivation for Participation in Citizen Science Scale were explored with post-hoc analyses to compare intrinsic participation scale items, extrinsic participation scale items, and total participation motivation score (Table 8). Intrinsic motivation score was not significantly different between new and experienced volunteers (p = 0.86), but extrinsic motivations and overall motivations for participation were both statistically significant (p = 0.02 for both).

Table 9: Comparison of Motivation for Participation in Citizen Science Scale survey items response scores between new and experienced volunteers.

Motivation Parameter	Level	N	Average	Std. Deviation	p-value
Intrinsic Participation	N	41	4.62	0.46	0.86
	E	34	4.60	0.48	
Extrinsic Participation	N	41	4.01	0.64	0.02
	E	34	3.65	0.65	
Participation Motivation Sum	N	41	0.61	0.63	0.02
	E	34	0.96	0.66	

Volunteers were given an open-ended survey question that prompted them to describe their main motivations for participating in Blue Thumb and/or monitoring a stream. Open coding revealed 3 primary motivators across both sets of volunteers included interest in learning about water quality (30% response), personal feelings or attachments to the body of water, or water quality issues in general (26% response), and desire to contribute to a project, the scientific process, or something “greater than themselves” (23% response).

Experienced volunteers reported motivation largely attributed to personal feelings or place-based attachments. Volunteers who had continuously monitored at the same site for the duration of their participation mentioned the connection they felt to these places. Many experienced volunteers described how "contributing" to something was associated with positive feelings, or a sense of responsibility and duty. An experienced volunteer said, "I have a deep passion for the environment and feel a duty to monitor and preserve these fragile ecosystems".

New volunteers reported more motivation for creating/maintaining social relationships between themselves, friends and family, or other Blue Thumb volunteers. One new volunteer said, "I want to personally engage in an established organization and surround myself with like-minded people". Another new volunteer said, "I want to be an example to my family of how to do this […] I want to be a part of a bigger community involved in water monitoring". Some volunteers, usually new volunteers and younger college students described participation in Blue Thumb as a way of gaining career-specific skills. As one new volunteer stated, "Eventually I want a career in something environmental, so I thought this was a good place to get started".

Additional reported categories of motivations included connection to land, career experience/skills, and education/outreach. Landowners were a small sub-group of volunteers in both new and experienced categories (n=8, Table 2). These volunteers indicated their personal connection to some piece of land was their main motivator, "I want to help protect water quality on family land that we own". Both groups of volunteers mentioned education or outreach as a motivation as well, for example "I want to help educate others and create an awareness of water quality issues".

Length of Participation

Linear regression analysis was completed on experienced volunteer data to assess how length of participation correlated to survey item scores (Table 9). A simple linear regression was calculated to predict behavior and stewardship, interest in science, motivation for participation, and motivation for doing/learning science scores based on number of years of participation. Across all variables, no statistically significant relationships was identified between identified outcomes and years of participation.

Table 10: Linear regression between years of participation and learning outcomes in experienced Blue Thumb volunteers.

Outcome	F	Numerator df	Denominator df	p-value
Behavior and Stewardship	0.11	1.00	29.00	0.74
Interest in Science	1.71	1.00	29.00	0.20
Motivation for Citizen Science	0.43	1.00	29.00	0.84
Motivation for Learning Science	0.18	1.00	29.00	0.67

Discussion

This research applied a framework for participant outcome evaluation from Phillips et al., 2018, and shared survey items, to assess how length of participation in Blue Thumb influenced participants behaviors, interests, and motivations. In contrast to expectations, changes in participant outcomes that were assessed were positive, but comparisons between new and experienced volunteers for many of the outcomes did not reveal significantly different results for behaviors, interest in science, and motivation for doing/learning science. Additionally, no significant relationship existed between any of the 4 measures and years of experience, further demonstrating that volunteers likely were interested and motivated before joining and remained so throughout their volunteer career. As seen in similar studies of participant outcomes, it is possible that the reason for this lack of results was due to the selective nature of *who* participates in citizen science (Crall et al., 2013; Elizabeth & Pateman, 2021; Trumbull, Bonney, Bascom, & Cabral, 2000).

When looking at volunteer demographic data, it was apparent that volunteers interested in Blue Thumb came from a strong science background, with higher levels of education that tended towards the biological/environmental sciences, who identified strongly as “pro-environmental”. The GESS results showed no significant difference in self-reported pro-environmental behaviors between new and experienced volunteers, suggesting that participation in Blue Thumb may do little to change or establish new pro-environmental behaviors. This study did not evaluate behavioral change for experienced volunteers, but rather demonstrates extent of current behaviors. Like pro-environmental behavior, interest may also be seen as a predictor of continued involvement: volunteers with higher established interests in nature and science may be more likely to continue to engage than those with lower scores. Future BT evaluations, evaluation should include open-ended questions about how BT has directly influenced any new or increased environmental behaviors. Theoretically, pro-environmental behaviors may be best understood as a predictor of volunteerism, rather than an outcome.

Both new and experienced volunteers demonstrated positive motivational scores on the two motivations scales (MPCS and MDLSS) which indicate predominately intrinsic motivations are at work (Phillips et al., 2017). Both groups of volunteers indicated that major reasons for participation included a general interest in water quality, personal feelings and attachments to specific place-based water sources, feelings of participating or contributing to something, and the creation of/maintenance of social relationships. In similar studies, it has been found that both place-based attachments and social aspects of volunteerism are often very important to long-term environmental volunteers (Church et al., 2019; Deci, Ryan, & Koestner, 2001; Domroese et al., 2017). Further, pro-environmental behaviors and attitudes combined with the desire to protect the environment have been cited as motivation to participate in many environmentally oriented citizen science projects (Chase et al., 2016; García-valiñas et al., 2012). Combined, both quantitative and qualitative survey items indicated that different combinations of intrinsic and extrinsic factors were important motivators for individuals to join and continue participating in Blue Thumb. For instance, a volunteer may participate in Blue Thumb because they enjoy being in nature and are inherently interested in water quality as a topic (intrinsic), but they also participate to contribute to environmental conservation efforts by collecting data samples (extrinsic).

A significant difference was found between new and experienced volunteers for their motivations to participate in citizen science (MPCS). Extrinsic motivators were more likely to be identified by new volunteers as compared to experienced volunteers. Many of the new volunteers were college-level students who were actively interested in pursuing a career in a science-related field, and therefore their motivation to learn was centered more on a desire to gain relevant skills and experience or learn new material. Conversely, experienced volunteers were more likely to describe how continuing to learn about water quality was important to them due to a mixture of personal feelings they possessed and attachments they had for the specific places they monitored. Similar studies previously done by Clary and Snyder (1991) and Jacobsen, Carlton, & Monroe (2012) also found that young people are particularly motivated by career-related motivations such as gaining skills, while older volunteers are more likely to share and pass on knowledge.

A key conclusion of this study was that context-specific differences between volunteer groups may not be adequately captured by quantitative survey items alone. In many cases, while quantitative scorings on surveys for behavior/interest/motivation reported by volunteers were not significant – qualitative responses provided more in-depth information as to *how* the type of behavior/interest/motivation between volunteers differed. Open-ended replies revealed further details about volunteers' participation in environmental behaviors, changes in interests over time among seasoned volunteers, and factors that motivated them to join Blue Thumb in the first place. Triangulation of findings, by combining quantitative and qualitative items, revealed a rich narrative about Blue Thumb volunteers. A growing body of research is starting to demonstrate that using a mixed methodology to evaluate programs gives researchers a more complete picture of what is happening within the program (Diaz et al., 2021; Lynch et al., 2018; Palinkas et al., 2019; Phillips et al., 2014; Phillips et al., 2017).

Another important consideration for future evaluation is the length of assessment. Instead of static evaluations with no set baseline, studying participant outcomes over time within the same person may be more informative. The findings of this research indicate that it is important to continue to monitor volunteers' behaviors, interests, and motivations throughout their continued participation. This research also showed that these outcomes among Blue Thumb volunteers are complex and vary over the time that a volunteer participates. Previous studies of all three outcomes have found mixed results, and this is likely the case of participant outcomes being complex and difficult to measure with either quantitative or qualitative tools alone (Asah, Lenentine, & Blahna, 2014). Volunteers are not homogenous, instead they change over time and therefore they should be monitored throughout the duration of their volunteerism to fully understand how participation influences desired programmatic outcomes (Deci, Ryan, & Koestner, 2001; Geoghegan et al., 2016).

This research has implications for evaluation of Blue Thumb volunteers in the future. Rather than comparing new and experienced volunteers, evaluation may be best approached in a three-phase assessment: 1) a front-end evaluation to establish pro-environmental behaviors, interests, and motivations to establish what baseline already exists within the new volunteer base, 2) formative evaluations during training or educational events to assess the impact of training on volunteer likelihood to engage in the program's desired outcomes (i.e., pro-environmental behaviors such as water conservation, participation in Blue Thumb programs), and 3) summative evaluation of experienced volunteers to determine whether Blue Thumb's target outcomes have been accomplished.

Limitations

An important consideration to the findings of this study are the locations in which Blue Thumb hosts training events. Nearly all training events captured in the duration of this research were held at public educational institutions, from regional colleges to public libraries, and largely attracted the local population with younger age and higher education demographics. Due to new participants' geographic ties to the locations of program-hosted events, a bias in the volunteer base may be introduced. The majority of volunteers at Blue Thumb training events were not from rural areas or underrepresented groups.

Due to the voluntary and recreational nature of Blue Thumb, the evaluation process was designed to take less than fifteen minutes to be 'both brief and engaging' (Nicholson, Wiss, & Campbell, 1994). Some of the survey items from Cornell were shortened, which may impact the integrity of each scale. Because new participants pay for the initial two-day training to be able to participate, it was not possible to have a directly comparable control group to compare new and experienced volunteers to. In addition, all new volunteers were able to be sampled in-person while only a certain select group of experienced volunteers opted to do the surveys on their own, which may have led to sampling bias. One avenue of evaluation that was not explored was surveying Blue Thumb participants who had completed a training event but had not continued with the monitoring program. Evaluation of these individuals may yield more information about the role of interest in volunteer recruitment and retention.

Conclusion

Future research would likely benefit from inclusion of mixed methodology in the process of programmatic evaluation, specifically adding qualitative assessments to provide context for quantitative findings. Even though the results of this study did not detect significant changes in many participant outcomes associated with participation, it is possible that these results reflect the limitations of using quantitative surveys on only Blue Thumb participants. Literature on citizen science evaluation suggests using a control group of non-participants where possible for more accurate comparisons, for a true experimental design as opposed to the quasi-experimental design of this study (Bonney et al., 2009; Eyler et al., 2009; Overdevest, 2004). Furthermore, it was demonstrated here and in previous studies that motivation is a highly complex construct that can be difficult to accurately capture with survey tools (Domroese and Johnson 2017; Mintz, Arazy, & Malkinson, et al., 2022; Porticella, Phillips, & Bonney, 2017; Raddick et al., 2013). Because volunteers change over time, behaviors, interests, and motivations change over time as well. Future evaluation should consider long-term studies that follow a volunteer throughout their volunteer experience to capture the full change in outcomes that occurs.

In summary, citizen science has been shown to have the potential to increase specific learning outcomes such as behavior and stewardship, interest in science, and motivation, both for participation in citizen science and environmental action (Bonney et al., 2009; Conrad & Hilchey, 2011; Crowston and Wiggins, 2011; Eyler et al., 2009; Haklay, 2013; Dickinson et. al., 2012b).

Assessment of participant outcomes is valuable not only to researchers, to understand how volunteerism benefits participants, but is also valuable to citizen science program managers for consideration in building or maintaining specific projects (Phillips et al., 2018). However, practical evaluation of these outcomes remains a challenge in this field. As demonstrated in this paper, more research is needed into the proper combination of assessment tools and techniques to accurately capture the influence of volunteerism on participants. More in-depth longitudinal studies of select participant outcomes may reveal more useful information about how volunteerism influences participants over time. This research was intended to explore new methodologies for assessing and evaluating this growing field of study.

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CHAPTER III

GETTING OUTSIDE: PLACE AS A MOTIVATOR IN CITIZEN SCIENCE ENVIRONMENTAL MONITORING

Introduction

Citizen science projects, or projects that involve members of the public in ongoing scientific research, are a form of research collaboration that engages volunteers in data collection, analysis, and dissemination (Haklay, 2013; Dickinson et. al., 2012; Conrad & Hilchey, 2011; Crowston & Wiggins, 2011). Citizen science projects encompass a range of research areas, from biological to environmental, that cover large geographical scales and obtain vast amounts of data that are otherwise unfeasible to acquire (Bonney et al, 2009). Environmental citizen science projects are often "data intensive" and involve the use of participants to collect data, from bird counts to identifying local pollinators (Alender, 2016). These projects often use citizen collected data and apply it to policy or management issues (Bonney et al. 2009). Several studies discuss potential beneficial outcomes for environmental volunteers, ranging from increased knowledge and awareness about environmental issues, to transferable skills, and changes in environmental behaviors and attitudes (Bonney et al., 2009). Evaluation of outcomes from participation in citizen science is often listed as a "high priority" for practitioners and program coordinators, yet it is commonly rated to also be one of the largest challenges. Motivation is one of the most evaluated outcomes among citizen science projects, as evidenced by the number of studies on the topic (Phillips, Porticella, Constas, & Bonney, 2018; Isaacs, 2017). Previous studies have indicated that volunteer motivations are complex and may be hard to accurately evaluate or capture (Porticella et. al., 2017; Rotman et al., 2014; Raddick et al., 2010).

Within the realm of environmental projects, water monitoring is a well-established branch of citizen science with over 1,800 projects and 8,500 volunteers monitoring streams, lakes, ponds, wetlands, and other aquatic habitats (Overdevest, 2004). Water monitoring projects have been sponsored in recent years by the Environmental Protection Agency (EPA) to assist states in the collection and maintenance of local water bodies (McKinley et al., 2017). In some states, volunteer collected data is used to publish reports on water quality (Alender, 2016). Studies into water quality monitoring project volunteers have demonstrated that volunteer motivations are pivotal to their continued participation (Alender, 2016). Volunteers who are highly motivated may go on to alter their own personal environmental behaviors, get involved in policy and management decision making processes, advocate for water bodies, or educate and spread awareness of environmental issues (McKinley et al., 2017).

Volunteers are crucial to the success of citizen science projects: not only in acquisition of data, but in promotion of social awareness and change (Alender, 2016; Bonney et al., 2009). As stated in Ryan et al. (2001, p. 629), “The environmental movement would not exist without the help of thousands of dedicated volunteers”. On a broad scale, environmental citizen science projects remain a cost-effective solution for sustaining long-term conservation strategies (Isaacs, 2017). While some papers describe volunteers as human sensors used to collect environmental data, it is important to note that volunteers are humans with complex emotions that drive their participation (Resch, 2013). Volunteer motivations are important considerations to the continuation of citizen science projects. Why these volunteers initially sign up and continue to participate in a citizen science project has implications for long-term retention. For citizen science project managers, understanding volunteer motivations will help to a) reduce efforts put into recruitment and retention of volunteers, while b) maximizing the benefits both participants and the project receive from their volunteerism (Alender, 2016).

Background

In Oklahoma, Blue Thumb is a state-sponsored citizen science program that focuses on water quality monitoring. Blue Thumb is the educational arm of the Water Quality Division of the Oklahoma Conservation Commission (OCC). The Blue Thumb program is the primary means by which the Oklahoma Conservation Commission addresses the Non-Point Source Pollution Management Plan (NPSMP) objective focused on education (Blue Thumb, 2019). Blue Thumb trains volunteers to perform monthly monitoring of creeks and streams. Water quality parameters tested includes habitat assessment data, dissolved oxygen, nitrate/nitrite concentration, ammonia, orthophosphate, and chloride. Long term volunteers may also continue in the program to collect biological data (macroinvertebrate and fish collections) and write data interpretations over their collective findings. This data, in turn, is presented publicly on the Blue Thumb website (www.bluethumbok.com) and is used by the OCC.

Blue Thumb remains intensively engaged with Oklahoma citizens with more than 80 streams monitored, over 300 active volunteers, and over 8,000 volunteer hours logged in a year. In a previous needs assessment, Blue Thumb identified that volunteer recruitment and retention are among top priorities (Olson & Colston, 2020). To enhance the volunteer experience, Blue Thumb program managers need to understand who volunteers to monitor water quality and why they continue to participate in the program. Place may have an important role in determining who participates in Blue Thumb. Despite being distributed across the entire state, most sites are concentrated in urban areas and are particularly concentrated in Oklahoma's central and northeastern regions (Figure 7). Sites are selected, in part, by both Blue Thumb managers and the volunteer base themselves. In some cases, volunteers join the program knowing which stream sites they are attached to and wish to monitor. In other cases, Blue Thumb managers assign a stream to volunteers who do not have a predefined site. In this study, we examine how repeated place-based environmental monitoring influences Blue Thumb volunteers' motivation to continue monitoring streams.

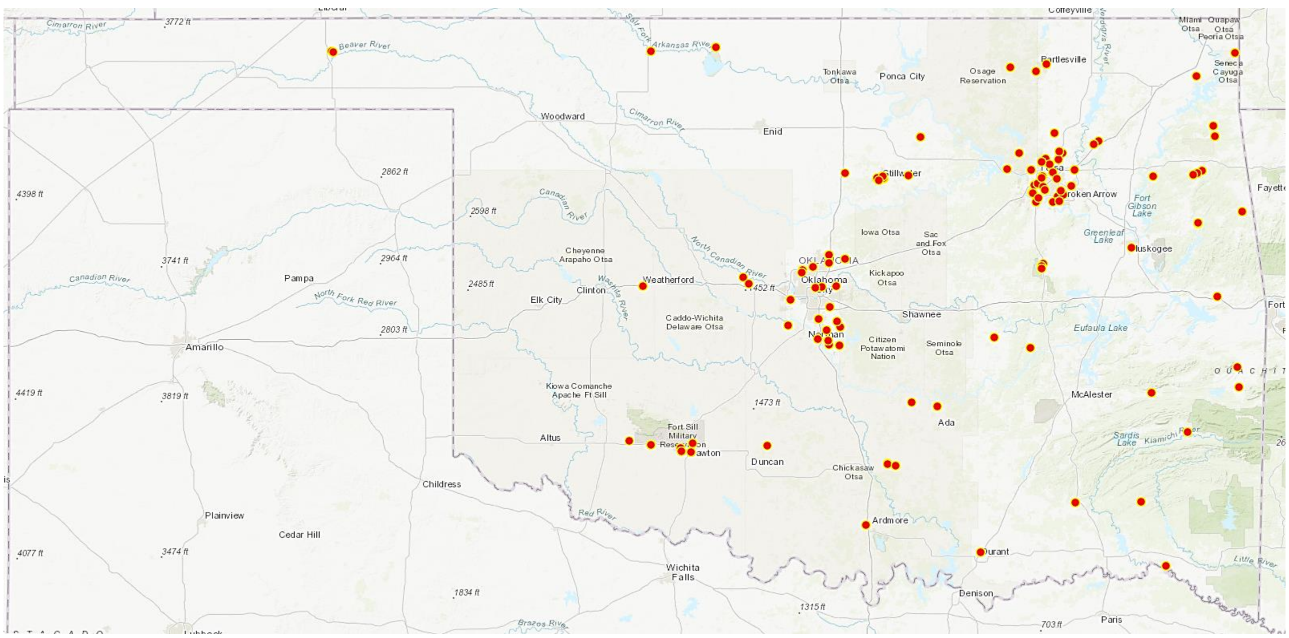

Figure 7: Blue Thumb's interactive data map. Each red dot signifies a designated and active sampling location, with available water quality data that can be publicly accessed.

Motivation and Place in Citizen Science

Motivation in Environmental Citizen Science

Motivation is a multifaceted conceptual construct that describes the act of setting specific goals to achieve a particular behavior or outcome (Phillps et al., 2018). There are many theories and frameworks used to describe motivation. Clary and Snyder (1998) described volunteer motivation as depending upon six major functions, with the top three being: *Values* (where individuals act upon principles that are important or valued to them – such as a volunteer who wants to "help" the environment), *Enhancement* (where individuals seek participation related to personal development, growth, and goals), and *Understanding* (where individuals want to learn/understand a concept). Other important functions of motivation deal with career opportunities (*Career*), social dynamics (*Social*), and personal feelings or attachments (*Protective*) (Clary and Snyder, 1999). While these categories have been used to create survey items, such as the Inventory of Volunteers' Motivations, these functions may not capture all aspects of motivation (Clary & Snyder, 1991; Isaacs, 2017).

It is common to research motivations for volunteering in general, but there are fewer studies that explore motivations for volunteering in environmental citizen science projects specifically (Raddick et al., 2013; Issacs, 2017). There are even fewer studies that examine the specific motivations involved in water quality monitoring (Alender, 2016). In a study by Ryan et al. (2001), researchers found that "helping the environment" was one of the major driving motivators for environmental citizen science volunteers. Research suggests that some motivations are project or topic specific. For instance, a volunteer who participates in water quality monitoring may be motivated by learning more about waterbodies or aquatic organisms (Issacs, 2017). In some cases, volunteers are more broadly motivated by contributing to science or engaging in the scientific process directly (Raddick et al., 2013; Domroese et al., 2017). A study on the Great Pollinator Project found that motivation for "helping or contributing to science" was the second top motivator (Domroese et al., 2017). Other research finds that volunteers may develop a "sense of place" in connection to the locations that they monitor over time (Gooch, 2003; Haywood et al., 2016). For instance, a volunteer may become motivated to collect data on a local body of water that they are familiar with (Alender, 2016). Even this list is not comprehensive, and researchers argue that more research needs to be undertaken to fully understand the extent of volunteer motivation.

It is also agreed upon by researchers that motivations influence processes that directly sustain volunteerism (Asah & Blahna, 2012). Alender, 2016, proposed that motivation is intrinsically tied to volunteer retention and engagement in a particular project. The quality of a project, that is the extent to which a project's goals and activities align to the needs and interests of the participants, can have influence on the quantity of participation, or the total number of participants and numerical data they submit (Alender, 2016). Additionally, in a study by Asah & Blahna (2012), researchers found that volunteers' frequency of participation was influenced by personal and social motivations. Understanding motivation educates citizen science program managers on how best to design projects that promote volunteer experiences and meet project goals. There is a need for further study on what drives, and sustains, participation in environmental citizen science projects.

Place Based Volunteerism

Any citizen science initiative that emphasizes monitoring or tackling environmental issues occurs within certain socio-ecological contexts (McKinley et al., 2020). Many scholars have become interested in understanding the complex relationships that exist between the outcomes of participants and the places that they monitor as a part of their specific program (Haywood, 2014; Lorenz, 2016; Edmonston, 2021). In environmental monitoring programs especially, participants often monitor in a repeated fashion at the same location for various amounts of time (Pocock, Tweddle, Savage, Robinson, & Roy, 2017). For instance, Blue Thumb volunteers monitor the same waterbody monthly throughout the duration of their participation.

This leads to new questions to explore about the relationship between the places volunteers monitor and their motivations for continued engagement.

In the realm of understanding when, how, and why learning occurs in citizen science it is also crucial to understand *where* the learning takes place. "Sense of place" is a concept derived from the field of human geography that has been recently used in a citizen science context to refer to the links between the experiences, social processes, and physical environment in which they occur (Haywood, 2014). The literature acknowledges that the concept of sense of place is used inconsistently depending on specific academic disciplines (Stedman, 2002; Masterson et al., 2017). This study uses the work provided by Haywood (2014, p.70) to define sense of place as "an experiential process created by the setting, combined with what a person brings to it". "Place" refers to a specific physical environment, where the individual's self and social-ecological connections overlap (Scannell & Gifford, 2010). Sense of place theory includes two major principal aspects: place attachment and place meaning. Place attachment is defined in this context as "the bond between people and places", whereas place meaning is used to refer to symbolic meanings a person subscribes to a particular place (Haywood, 2014, p. 70).

Place attachment is a concept that includes an individual's identity of self, their physical or social dependence to a place, and the emotional connections they may have to some aspect of the environment (Hildago & Hernandez, 2001). The length of time a participant spends in a particular place, as well as the intensity and duration of the time spent there, have been seen to be predictors of level of place attachment (Haywood, 2014). Place attachment is further divided into four major subcomponents: place identity, place dependence, place affect, and place social bonding. Place identity refers to the degree to which a place is included in an individual or collective identity (i.e., feeling that a particular place is "a part of you"). Place dependence refers to the needs (physical, emotional, spiritual) that a person has fulfilled by a physical place. Place effect is defined as the specific emotional bonds formed between a person and place. Finally, place social bonding is concerned with the degree of attachment to a place that forms due to social interactions within that place.

Theory and Research Questions

This research used the place attachment (PAT) model first proposed by Raymond et al. (2010; Figure 1, p. 425) and then later updated by Haywood et al. (2020; Figure 2, page 56). In this model, place attachment is set in the context of hands-on, outdoors citizen science and imagined with three dimensions, each with sub-constructs: personal context, community context, and natural environmental context (described in Table 11). The researchers of this model suggest that application of place attachment theory to volunteers can increase the potential for understanding the ways in which people-place relationships facilitate and sustain engagement in citizen science (Haywood, Parrish, & He, 2021).

Table 11: Summary of the major constructs of place attachment model updated by Haywood, Parrish, & He (2021).

Dimension	Major Constructs
Personal context	1. *Place identity* Attachment based on some aspect of identity of person, connected to place 2. *Place dependence* Attached based on functional dependence or service performed by place
Community context	1. *Family/friend bonding* Attachment based on sense of belonging or value of family or friend group 2. *Social rootedness* Attachment based on sociocultural relationships
Natural environmental context	1. *Nature bonding* Attachment based on connections to the living world experienced at the place 2. *Environment bonding*

Attachment based on non-living or physical aspects of the environment experienced at the place

3. *Science affinity*
   Attachment based on how a person uses science through citizen science experienced at the place

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New questions are being posed as to what relationship sense of place has to intended participant outcomes, such as stewardship and motivation, and volunteer retention. A few studies have shown causality between a sense of place and pro-environmental behaviors, like recycling (Vask & Kobrin, 2001; Halpenny & Cassie, 2003). Other studies have investigated the role of sense of place to volunteer motivation with mixed results. Measham and Barnett (2008) published a study that found place attachment to be one of several main motivators for environmental volunteers. Gooch (2003) also found that a volunteer’s sense of place was connected to the formation of an ecological identity, where citizen science participants strongly identified with the physical locations where the volunteering took place. Information about how volunteers perceive a sense of place can be used by program administrators to better design citizen science projects that cultivate a sense of place among specific volunteer groups.

Study Purpose

Using the PAT model developed by Haywood et al., the current study aims to investigate how different types of place attachment between Blue Thumb volunteers and the stream sites they monitor influence motivation and retention (2020). Although volunteer motivations have been studied numerous times, few studies attempt to explain specific motivations as they relate to place in citizen science projects. Environmental citizen science projects, which involve participants spending time in nature, raise new questions to be explored about the role of place in motivation. It is important to address how geography and how location-based volunteering is perceived by the very individuals who participate in citizen science efforts. Knowledge of place-based motivation may be helpful for citizen science researchers and program administrators to understand how to enlist, captivate, and keep volunteers in programs that emphasize repeated experiences in nature.

Methods and Data Analysis

Sampling Procedures

This research used qualitative semi-structured interviews to examine motivation and place-based attachment across volunteers in Blue Thumb. The sampling methodology that was used in this phase of evaluation was maximum variation sampling, which is designed to look at a subject from all available angles to reach a greater understanding of the issue (Wu Suen, Huang, & Lee, 2014). A list of long-term and active volunteers was generated by Blue Thumb administrators, who then placed volunteers into different learning community typologies (university, students, landowners, hobbyists, and more) to capture diversity in both participants and sites. Blue Thumb contacted these volunteers to ask for their participation in this study.

Volunteers who participate in Blue Thumb's stream monitoring program have an assigned stream location that they monitor monthly. Volunteer criteria inclusion characteristics included: they were 18 years or older, they had completed the required two-day Blue Thumb training, and had volunteered for a minimum of one year to ensure repeated visits to their assigned site. Initially, 25 participants identified by Blue Thumb as active volunteers across a range of backgrounds were purposively selected to participate in this study. Due to scheduling or personal conflicts, 5 of the participants were unable to complete the initial interview and follow up process, therefore a total of 20 participants were included in this study.

Semi-structured Interviews

Semi-structured interviews were designed to provide open-ended responses that probed volunteers about two main themes: place attachment and motivation for participation (Appendix B). Place attachment questions focused on the relationship between the monitor and their stream they were assigned, the emotional, physical, or spiritual connections that they had to that place, and the degree of attachment they felt to their stream. Motivational questions focused on how volunteers are involved with Blue Thumb, their major motivations for continued participation, the role of place on motivation, and individual volunteer experiences. Interviewees were additionally asked to reflect on their motivations throughout different steps of participation, from training, to initial involvement, to retention. Finally, questions at the end of the survey addressed potential barriers to motivation that volunteers identified.

Data Coding and Analysis

Once completed, interviews were transcribed and de-identified to protect the name of individual group members or stream sites. Transcripts were then read through and coded into categories based upon shared themes or experiences. Data analysis was performed using thematic analysis procedures (Braun & Clarke, 2006). The researcher conducted and recorded interviews, wrote and reviewed memos across the interview process, and transcribed interviews. After transcription of all interviews was completed, interview documents were transferred to QDA Miner Lite software. Codes were created in vivo, where possible, to retain participants' voice in the analysis process. Next, a thematic coding process was guided by the Haywood et al. (2020) PAT model. Interview codes were aligned with the three dimensions (personal attachments, community attachments, and natural environmental attachments) and major constructions of each. An example of the coding analysis process is shown in Figure 7. Additionally, a summary of themes, categories/sub-themes and sub-categories is shown in Figure 8.

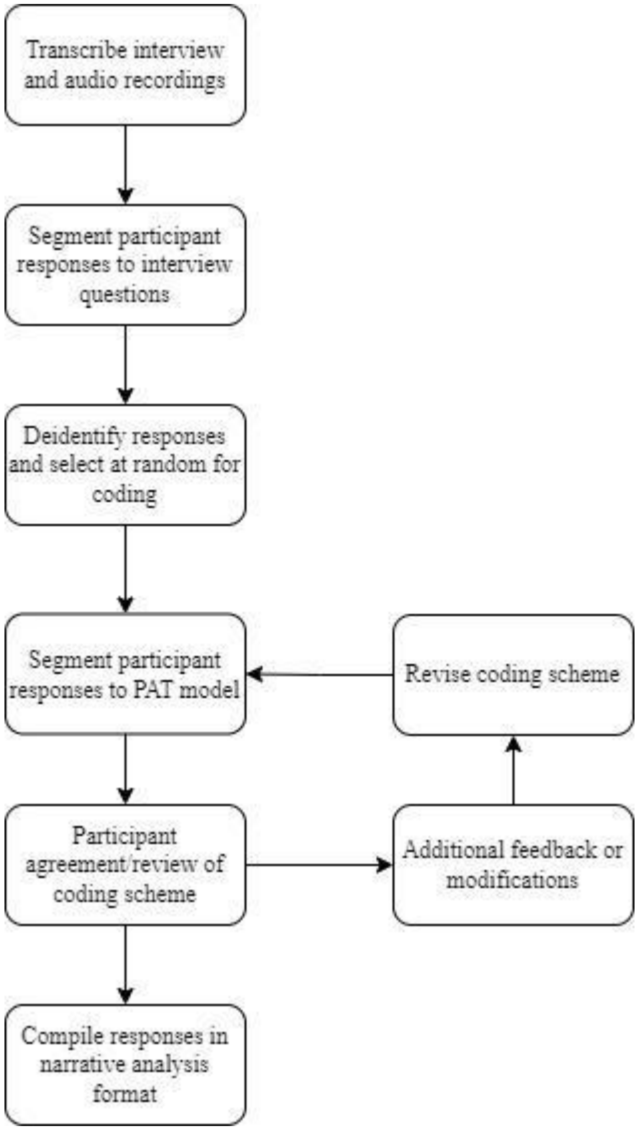

Figure 8: Coding process used to generate final coding themes.

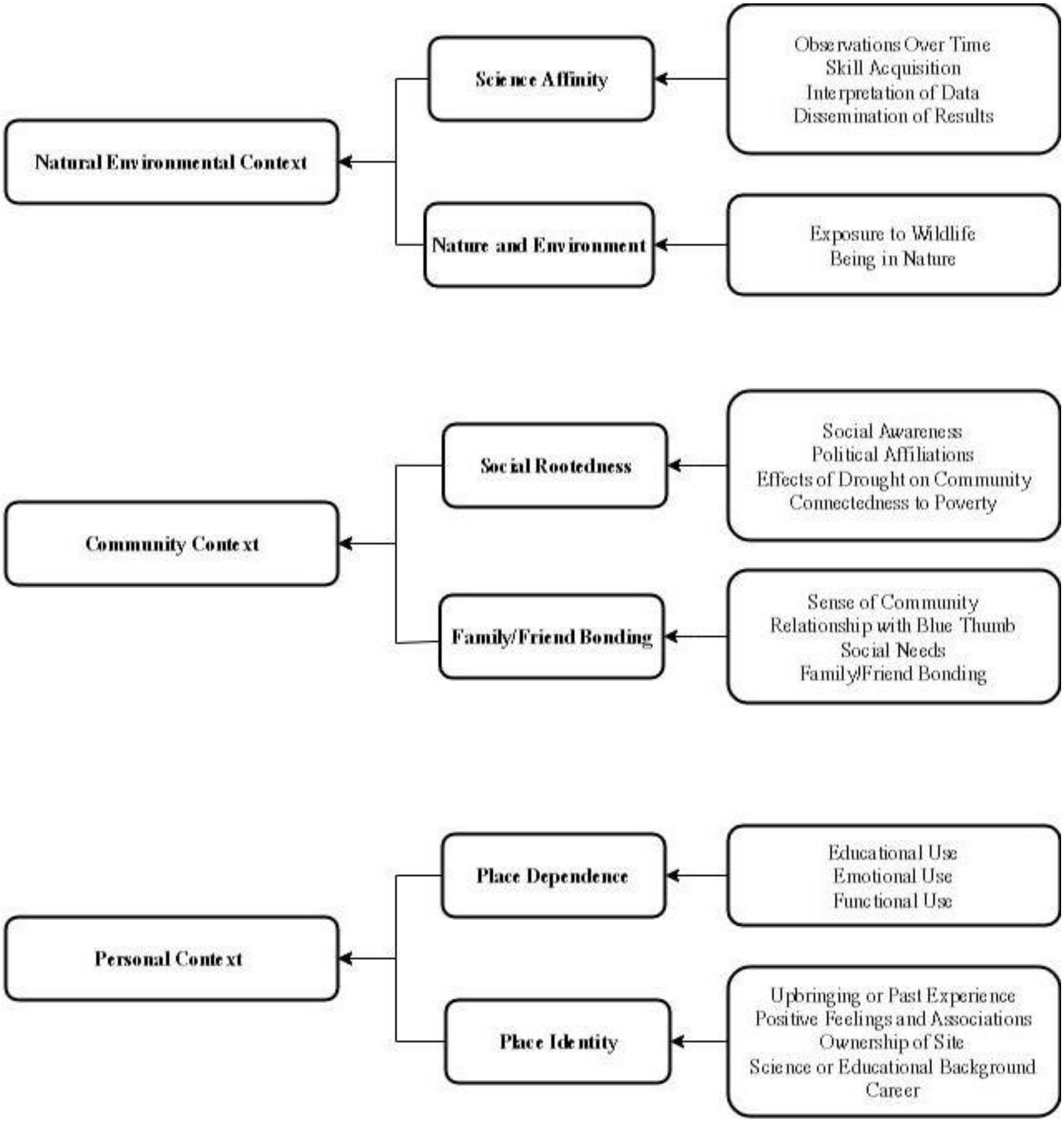

Figure 9: Generated themes and analysis relative to the PAT model in Haywood et al., 2020.

To maintain academic rigor, this study employed several procedures including prolonged engagement, reflexivity, and member checking. The primary researcher engaged in Blue Thumb activities and monitoring for a calendar year while this research was being conducted: from the initial training process, to actively monitoring a stream, and engaging in Blue Thumb community events to meet and become familiar with both volunteers and the Blue Thumb program. To maintain objectivity and reflexivity, the primary researcher engaged in making notes and memos about participant quotes and researcher thoughts during the initial interviews and considered the way in which their interactions with participants might be influenced by their own personal experiences (Koch & Harrington, 1998). Finally, member checking was employed at the end of the coding process to ensure participant experiences were not misconstrued (Carlson, 2010). A transcript of coding with participant quotes and researcher memos was shared with the initial participants to illicit feedback. A subsample (n=13) responded to this follow-up request and added additional information or modified previous statements to better reflect their motivations.

Results

Demographic Summary

Demographic data of the volunteer pool is included in Table 12 below. Participants included a nearly equal spread of men and women above the age of 18. Volunteers who participated in this research were over a mean age of 40. All but 2 participants involved in this research had one or more degrees in higher education. This demographic information was an important consideration, as previous evaluation of new Blue Thumb volunteers had shown that younger, female college students are often the most numerous participants. Participants were asked for the total length of participation, defined in years from when they first began monitoring a stream to the present time. Volunteer participation ranged from a minimum of 1 year to over 25 years.

Table 12: Demographic information for Blue Thumb participants who completed motivational interviews.

Demographic	**Sample**
Sex	
Female	9
Male	11
Age	
>=24	1
25 to 39	1
40 to 60	6
60+	7
Education	
Some College	2
Bachelors	6
Masters	7
Doctorate	5
Career	
College Professor	8
College Student	1
Government Employee	4
K-12 Teacher	3
Landowner	2
Scientist	2
Length of Participation	
0 - 5 years	8
6 - 11 years	1
>=12 years	4

Place Attachment (PAT) Model

Overall, participants expressed a range of attachments and motivations associated to the specific streams and places that they monitored for their volunteer work with Blue Thumb. The first section includes the ways in which participants expressed motivation as it aligns with the three dimensions of the PAT model. The second section reports perceived barriers to participation that inhibited volunteers' overall motivation or enjoyment.

Personal Attachments and Motivations. The Personal Context of attachment and motivation described by Haywood et al. (2020) is defined as dimensions of self that are connected to place, and the functional connection based on intended use of a place. This category was found to be relevant to 36% of participant replies. Coding of participant responses showed some level of motivation or attachment based on a) aspects of the participant's self-identity (such as connection based on participants upbringing, educational or career background, or personal identity), and b) a function or service provided by the place where monitoring occurred (for example, a stream that connects to a body of water used for public drinking).

Interview responses revealed that most volunteers (75%) associated a major reason for continued monitoring with positive feelings based on their participation. Some positive feelings were related to the specific site that was being monitored, as with one landowner who felt "very attached and excited originally because of the family history that is there". Others reported positive feelings were broader and focused less on the site being monitored and more on feelings of contribution. Some volunteers described feeling "enjoyment", "happiness", and feelings of "pride" in doing a service or contributing their time to an organization, such as with the participant below:

> [Monitoring] just gives me a good feeling. I think that what I am doing is something that needs to be done … At the end of the day, I feel like I have made a contribution and that is gratifying to me.

In addition to having pleasant feelings and associations with their sites, some volunteers (30%) also showed a strong sense of ownership and personal attachment to each of their monitoring spots. Many volunteers used possessive terminology throughout their interview such as “my stream”, “our site”, and “my place” – though ownership (aside from the two identified landowners) was non-existent for these locations. Similar to this, many referred to their stream site as a live, aware person that they felt some sort of connection to. Several volunteers describing the relationships that formed between the volunteer and “their site”. One volunteer described his experience as,

> When you monitor a creek for that long, it’s almost like it becomes a living thing. You start to look at it as if it’s alive, and something you want to take care of. It’s kind of like, ‘How are you today?’. It’s an old friend, now.

Motivation for monitoring was related to some aspect of personal identity for many volunteers centered on either a) a background in science (70%) or b) a career that was perceived to be benefit in some manner from their participation in stream monitoring (50%). Most participants involved in this research had, at minimum, one or more degrees in higher education. The overwhelming majority of degrees that were held across participants were science-related with an emphasis in environmental science (ranging from botany to wildlife ecology to environmental chemistry). Some volunteers felt monitoring involved them in activities relating to their educational background. According to one volunteer, "I retired… My background is more in biology and general science. I think I was motivated to keep my hand in environmental work somehow by doing the [monitoring] out there". Another described the experience of monitoring as "keeping up to date in my field". Others identified that the skills they received through their repeated monitoring were useful to either current or future career aspirations.

Over half of the volunteers (60%) indicated that their monitoring experiences at their sites contributed to educational possibilities for students, ranging from K–12 to college level. Educational experiences with students were often associated with positive feelings of attachment for volunteers. Participants described how "students get excited" by monitoring and this in turn increases the volunteer's own excitement and desire to participate. Some educators created and implemented curriculum that specifically incorporated Blue Thumb monitoring and data from a specific site location into coursework. In this way, volunteers act as facilitators at a specific site encouraging students' scientific exploration. One educator described their main motivation for monitoring as such,

> I teach, and I do use Blue Thumb in my class. The whole concept behind teaching a science class is to get the kids to think in a scientific fashion. I'm going to throw real world data at [them]. These kids have never been in a creek. I give them this data, I take them to the site, and it opens up a discussion on what we're doing. I think [monitoring] is a wonderful way to get kids into science.

The last major identified theme related to Personal Context attachment to place was functional purpose of the sites that volunteers monitor. Half of respondents connected their motivations for monitoring a specific site to the service or function that site had for the community or watershed at large. Several of the monitored sites were identified by participants as either being used by urban areas to drain stormwater (e.g., "This creek was straightened out, and the city uses it for stormwater delivery… Water flows through the town, into the creek, and makes its way out") or as bodies of water that connected to a drinking water source (e.g., "It's an artery into the lake, which is the drinking water source for our town"). Volunteers expressed concern about monitoring water quality to ensure that continued functional use and public dependence on this body of water would be protected.

Community Attachments and Motivations. The Community Context of attachments and motivation focuses on feelings of belongingness to a group, such as Blue Thumb, and the emotional connections made between people. This category of attachment accounted for 32% of responses. Community Context as a coded theme included motivation or attachment based on a) a sense of belonging developed within a social setting with a friend/family group (such as a volunteer who monitors because of a family member's participation), and/or b) social rootedness, wherein sociocultural aspects shape the volunteer's participation.

The majority of respondents (85%) expressed a desire for social awareness regarding water quality in volunteers' local areas. Most volunteers discussed an increase in their own awareness of water quality issues since beginning to monitor with Blue Thumb, and thus their motivations evolving to an interest in "spreading awareness" about the state of water resources in Oklahoma. Volunteers located in urban areas felt that many people did not know a) what water bodies were present in their local cities, and b) what services or functions those waterbodies had for the people living near them. Many talked about a desire to "motivate" and "inspire" other people to become "involved" and "aware" of environmental issues near them. "I want to motivate and educate others, inspire them to do something similarly" one volunteer said, "[They'll] learn about the ecosystem and then do something about it".

Among volunteers who were located in the western part of Oklahoma, where drought events are more frequent, the subject of lack of water supply emerged as a subset of social awareness. Volunteers from this portion of the state wanted more awareness brought specifically to the issues caused by a deficit of water, "Where we are in the Ogallala aquifer, water is a problem. Water needs to be monitored, sensibly used, and there needs to be an awareness of its value". One volunteer told a story about growing up in the panhandle of Oklahoma with a lack of consistent water availability, and how that caused them to be motivated to spread awareness.

> I remember the well off the kitchen porch where you drew a bucket of water and boiled it if you wanted to consume it… [It] went dry every year: a good year it would go dry in August, but on a bad year it went dry in May. So, you're stuck living out of 5-gallon buckets of water, and that's what you consume… I've experienced drought where the lakes were below capacity, and everyone was struggling… Water is such a precious resource. The key is to let people know.

Community Context includes the social bonding that took place as a part of spending time with others and establishing ties while monitoring. Over half of the volunteers (60%) associated their monitoring experiences with social time spent with family, friends, or colleagues. Family members were the most reported social relationship related to monitoring, as many volunteers took partners, spouses, children, and grandchildren with them to monitor. Some volunteers described their motivation for monitoring as a way to spend time with family, "My wife and I wanted to adopt the creek that ran adjacent to the playground at our children's' school, (…) we thought it would be a good family outing: beneficial to the kids, and beneficial to ourselves".

Some volunteers claimed that participating in site monitoring with others satisfied a social need they had. Participants talked about how mingling, interacting with the public, and talking to other volunteers inspired them to be a part of Blue Thumb. For one volunteer, their main motivation was just socializing with the other volunteers that they participate with at one site location every month, "My motivation is that it's a social event between a farmer, a landowner, and a guy who wants to join them. We have a good time together". Some volunteers described public interactions that often occurred at the specific sites that they monitored, as people's interest was generated by seeing the volunteer performing Blue Thumb protocols. "You get to interact with someone on occasion, actually I'm hardly ever down there by myself" said one volunteer.

The perception that monitoring as part of Blue Thumb was creating a sense of community was significant to more than half of the volunteers (55%). Another volunteer described their feelings as, "I definitely feel like part of the Blue Thumb community now (….) Now that I know a lot of people, I feel like I'm a part of the group. A larger community of like-minded individuals". Of those volunteers who desired community, 63% especially mentioned how their connections with Blue Thumb personnel had inspired them to keep volunteering. Participants often interact several times with Blue Thumb staff throughout a monitoring year. Volunteers attend two macroinvertebrate collection sessions with staff annually at their designated sites and are invited to participate in macroinvertebrate identification after. Volunteers also interact with staff during quality assurance testing once a year, generally at a different location than their monitoring site. Many volunteers additionally sign up for optional educational events. Some comments about the importance of relationship with the staff included, “It’s a really good group of people, and I enjoy it. I’ve become close to [Blue Thumb staff] because I’ve known [them] for years now. I look forward to, and enjoy, catching up with them”, “I always look forward to talking to [staff] at our bug picking events”, and “I have personal involvement now with [staff member]”. Some participants would like more information about what was happening at other locations across the state or opportunities to interact with other volunteers. One participant proposed the idea of a statewide meeting to connect Blue Thumb volunteers,

> I think it would be interesting if there was a statewide annual meeting of all Blue Thumb volunteers. I just want to see what other volunteers are doing, which streams are being monitored, to get a bigger picture of the whole thing. Right now, it’s just me and my one site.

Natural Environmental Attachments and Motivations. Finally, 32% of participant responses identified with the Natural Environmental Context of attachment and motivations proposed by Haywood et al. (2020). This aspect of attachment focuses on the relationships formed between volunteers and the physical environment that was monitored. Three thematic categories were revealed during coding within this context and include a) connections to nature, or the living world, experienced at the monitoring site, b) connections to the environment or non-living aspects experienced at the monitoring site, and/or c) the experience of performing scientific activities through the Blue Thumb stream monitoring process.

Nature and Environmental attachment were supported by the two motivational themes that were most frequently reported and had to do with nature, a) exposure to animals (70%) and b) being in nature (60%). Many participants mentioned an interaction with animals when asked to recall something that inspired them at their site. As Blue Thumb volunteers monitor their stream, they become aware of the living organisms that rely on that body of water. Encounters with deer, birds, snakes, and fish left lasting impressions and positive feelings for volunteers. Some volunteers described their enjoyment of wildlife.

> I saw my one and only Painted Bunting there. The colors were so sharp and brilliant! That was aesthetically pleasing. I look at the shape of the beaver tracks in the water, racoon tracks in the silt, and I find that kind of thing enjoyable.

> I'm like a giddy kid. I enjoy stomping around and seeing what is living there. I'm a plant person, so I stop and look at the trees and the flowers. I'm just so giddy. I want to be the one looking at the macroinvertebrates, the fish.

Similarly, over half of the participants also described their motivation for monitoring to "get out in nature" and enjoy their physical site location. A strong motivator for Blue Thumb volunteers was to spend quality time outdoors. One described the experience, "Monitoring takes me outside, forces me to go out and spend time there. I'm often surprised at what I see". Volunteers used words like "peaceful", "tranquil", "serene", and "quiet" to describe the atmosphere of their monitoring site. When describing their site, one volunteer stated, "It's a little wilderness. Even though I was [sampling] under a bridge, it still felt like it was just me and nature". While another volunteer similarly reported,

> The sound of trickling water, I find to be peaceful… I enjoy going out there because it gets me away from a phone, computer, away from work. There's a sense of peace you get out there in nature. It can take the weight off your shoulders for just a little while.

Volunteers also spoke about motivation based on participation in the scientific process, defined as "science affinity" (Haywood et al., 2020). Commentary from participants about involvement in science included observations, skill acquisition, data collection and interpretation, and dissemination of results. First, several Blue Thumb volunteers described a desire to "observe changes" at their monitoring site as a reason for consistency in monitoring. From fall to spring, many volunteers made comment about how the physical (and even biological) nature of their site changes, and these changes motivate them to continue returning to the same location, "It's interesting to get out there every month, because it changes so drastically from summer when its lush to green to now. I like being outside and seeing the changes that happen in this same place over time". Skill acquisition, defined here as gaining a new skillset, was also discussed. Volunteers felt that through their continued monitoring efforts they gained experience in environmental science or conservation assessment and monitoring techniques.

One of the most discussed aspects of science from participants was a focus on the value of data collection and interpretation. Combined, this aspect was discussed by all 20 participants. Many of the Blue Thumb volunteers who had participated for several years felt a continued motivation to participate because of the length of the data sets that had been accumulated for their particular site, as with one volunteer who said, "I think the monitoring is good, especially when there is more than 20 years of data on it. Good data. I'm a scientist, so collection of data over time is just really important to me". Similarly, another volunteer reported, "I think having a long set of data is pretty valuable. If you have 18 years of data, you don't want to turn your back on it".

A subset of motivation based on data (45%) included the value of or need to disseminate the results of monitoring. Nearly half of Blue Thumb volunteers felt that it was important that data and information regarding their monitored site was spread with a) the local community, b) policymakers, and c) other Blue Thumb volunteers. Some of the participants described reporting their monitoring results to the local city governance, especially when there were community concerns about water quality or infrastructure. Many of the volunteers opted to participate in extra voluntary educational events to try and raise awareness in the local community about their streams condition.

Barriers to Participation

As a final part of the interviews, participants were asked to identify any potential barriers to participation which influenced their motivation or ability to monitor at their stream site. Roughly 65% of Blue Thumb volunteers had at least one identified barrier to participation within two emergent themes: 1) accessibility of monitoring site, and 2) use of technology and data.

First, accessibility of the physical location that Blue Thumb volunteers monitor was a common concern for many, especially older volunteers. Several of the participants reported that they had changed which streams they had monitored, at least once, due to difficulty in accessing the site. Blue Thumb volunteers were concerned at site conditions (such as steep embankments and slick rocks) and the potential for injury. Two participants reported injuries they sustained while monitoring that made them less likely to continue participating at the same location, with one describing it as, "I had to abandon [site] because the shoreline was getting too precarious…The shoreline […] collapsed around my leg and trapped me there. I needed to find a creek that was easier to get to". Several volunteers who switched monitoring locations spoke of how much they "missed" their starting location. Accessibility of site also included limited participation due to the locations of Blue Thumb trainings. Several attendees indicated a desire to engage more in regional events after feeling "excluded" by main events, which were frequently hosted in more metropolitan areas of the state.

Second, limitations and barriers to technology and data included a) a desire to use more sophisticated measuring equipment and b) ability to access and use volunteer collected data. Some Blue Thumb volunteers questioned the validity of the current equipment used to monitor and expressed frustration at the amount of time and set up that this equipment required. While acknowledging the difficult of price, many still wondered if there was technology available to gain more accurate data. One volunteer stated,

> It would be nice if there was an electronic device or some way of measuring these things. Every time we meet to do our testing, we question the possibility of updating or upgrading, or higher tech, for the testing kits… We wonder if there are more advanced ways to do the same thing.

Regarding data, some Blue Thumb volunteers described difficulty with the way that data is collected from and distributed to volunteers. In previous years, Blue Thumb volunteers had collected data on printed PDF sheets and then scanned or typed these and emailed them into the Blue Thumb staff. Within the last year, Blue Thumb had updated their data entry to a web portal that could be accessed on a mobile device. While volunteers described that they were "happier" with the update to the data entry process, many reported that they did not fully understand how to enter, or retrieve, data from this portal. A smaller subset of volunteers desired to know how data was being used, either by Blue Thumb staff or other agencies, and wanted to know that their monitoring "made a difference".

Discussion

Responses on the role of place in volunteerism gives context to the motivations driving Blue Thumb volunteers. For those who participate in Blue Thumb, stream sites that they monitor are places that hold multiple meanings and motivate volunteerism in different ways. It was apparent in the interviews that place played an important role in Blue Thumb volunteers' decision to continue participating. Blue Thumb volunteers' motivations are discussed below within the context of the PAT model (Haywood et al., 2020).

Personal Attachments

Many Blue Thumb volunteers were concerned about the state of the environment, specifically water quality issues, and felt motivated based on those feelings. In studies by other researchers, concerns about the environment have also been ranked among one of the top motivators for environmental citizen science volunteers (Geoghegan, Dyke, Pateman, West, & Everett, 2016; Asah & Blahna, 2012). Isaacs (2017) found similar results in a study of water quality monitoring citizen science volunteers, where the most important concern for volunteers included concerns over the health of a local river. Multiple Blue Thumb participants expressed a desire to volunteer based on Personal Context attachments to specific locations that they were familiar with and desired to study (i.e., family-owned land that had a stream, a frequently visited park, or the main source of drinking water for their community). However, some participants expressed concern for environment that did not depend on specific sampling locations. Instead, some volunteers envisioned the place they were concerned with as being broader and encompassing more than singular site (such as "all freshwater" or "all water sources in Oklahoma").

Several Blue Thumb participants explicitly stated that their continuous engagement was motivated by feelings of "contribution"—either directly to Blue Thumb or to their community. Okun (1994) found that three most frequent reasons for volunteerism included "helping others", "feeling useful or productive", or "fulfilling moral responsibilities". Similarly, volunteers with Blue Thumb highlighted how a desire to "give back" and a sense of "responsibility for the environment" drove them to keep monitoring their local waterways. Volunteers felt that their contributions were “making a difference” and this satisfied personal needs or goals they wanted met. Many volunteers expressed that not only were positive feelings or associations attached to the act of participation, but even aspects of self-identity and worth were connected to the places they monitored. Descriptions of motivations from volunteers reveal that many identify their monitoring efforts at a stream site as a means of connecting their interests in volunteerism with their educational or career backgrounds. This research matches previous studies into volunteer retention, which suggest that volunteer’s development of role identity and feelings of personal satisfaction encourage volunteer participation (de Vries, Land-Zandstra, & Smeets, 2019; Rotman et al., 2012).

When asked about barriers and limitations, Blue Thumb volunteers expressed a strong desire to know more about the outcomes of their monitoring efforts. Blue Thumb volunteers desired to see specific findings of the site they personally monitored, to know how conditions had changed at the site throughout the duration of their participation. Volunteers who monitored in places that were self-identified as functionally important, such as water bodies that were used for drinking resources, were motivated by knowledge of how their monitoring efforts contributed to continued use of this waterbody. Volunteers who considered their stream site to be functionally significant indicated that they were more likely to look for opportunities to share and disseminate their findings, such as at neighborhood council meetings or in-person meetings with city managers. In describing environmental barriers, volunteers indicated that the accessibility of places outdoors can sometimes be a hinderance. For instance, volunteers were concerned about their ability to monitor sites that were difficult to get to due to physical habitat, bodily limitations, or weather events. People with disabilities, and those with physical age-limitations, are underrepresented in environmental volunteering in part due to a lack of accessible environments of study (Ockenden, 2007). This finding emphasizes that it is important for citizen science program managers to consider the "place" in which their project happens: that is, providing opportunities for volunteers to be in environments that they are comfortable in.

The results of this study show how crucial personal and emotional ties that form between volunteers and their monitoring sites are for retaining volunteers. Blue Thumb volunteers demonstrate that repeated experiences at a particular site during monitoring generate emotion and meaning that encourages volunteer engagement. This study confirms several previous studies that have found that personal interest is one of the leading motivators for citizen science participants (Raddick et al., 2013; Domroese et al., 2017; Issacs, 2017). The findings of this study indicate that environmental volunteers care about a site's location as well as what it is utilized for (its functional dependency). In terms of site selection, this has ramifications for how environmental monitoring programs are designed. This study builds on earlier research that showed volunteers are more inclined to continue participating if they feel their efforts are not only valued but are functionally useful (Lopez, 2021; Geoghegan, Dyke, Pateman, West, & Everett, 2016; Wright, Underhill, Keene, & Knight, 2015).

Community Attachments

The results of this study indicated that raising community awareness about water quality issues was an important motivator to Blue Thumb volunteers. Volunteers shared their opinion that the public was unaware of the environmental problems regarding water quality and that streams were frequently disregarded. Motivation to increase public awareness was related to the specific places that sites were located. Volunteers who monitored in rural regions and western Oklahoma, where environmental factors like drought have a large impact on community water quality and availability, indicated they were more driven to raise community awareness. Participation in environmentally oriented citizen science projects has been found in other studies to promote awareness of environmental issues in local communities for volunteers and plays an essential role in the continuation of citizen science projects (Boney et al., 2009; Capdevila et al., 2020; Lee & Zhang, 2020). Many environmental volunteers become advocates or "stewards" of their local environments, sharing information that they find with their communities (Busch & Kaspari, 2013). In a similar vein, several Blue Thumb volunteers explained that the reason they stayed involved in monitoring was to help their local communities become more knowledgeable about and involved with public water resources.

To some volunteers, "place" was less of a geographical location and more of a social experience had during the process of monitoring a stream site. Many Blue Thumb volunteers indicate that they often monitored with a partner, whether that be a family-member, friend, or additional Blue Thumb volunteer. In some cases, volunteers thought that their motivation for monitoring was more about fostering and preserving relationships between people than it was about a particular stream site being monitored. As shown in numerous previous studies of citizen science engagement, Blue Thumb participants expressed a desire for a feeling of community and belonging and cited these as critical to maintaining their participation (Rotman et al., 2014; Rotman et al., 2012). A unique finding of this study was that social interactions between Blue Thumb administrators and participants was seen as an important motivator for future participation. Volunteers claimed that over time, via their shared, recurring experiences monitoring at a site, they developed relationships with Blue Thumb administrators. Volunteers also stated that their continuous affiliation with Blue Thumb was closely linked to their plans for future engagement in program activities.

The importance placed by volunteers on community-based attachments has many implications for environmentally based citizen science programs. First: many environmental citizens science projects require volunteers to be self-motivated, and to collect environmental data alone. This could potentially be discouraging to volunteers whom social attachments are more important motivators (Jones, Childers, Andre, Corin, & Hite, 2018; Kragh, 2016; Eveleigh, Jennet, Lynn, & Cox, 2012). Second: volunteers may build a sense of belonging and develop social identity in a citizen science community based on social interactions had with other volunteers and program administrators throughout the length of their participation (Lave, 1991). Because volunteers indicated that community, and sense of belonging, are important, citizen science program managers should attempt to create activities that build a sense of community and allow volunteers opportunities for communication (Manatschal & Frietag, 2014). Conferences, seminars, and volunteer appreciation events are just some examples of active participation strategies that can help link volunteers over vast geographic distances and promote social ties.

Natural Environmental Attachments

Being exposed to wildlife and the natural physical world outside of their usual setting was a big incentive for Blue Thumb volunteers. One of the few encounters many volunteers had with what they considered to be the "natural environment" was the time they spent monitoring a stream site for Blue Thumb. Being in nature created emotional connections for volunteers, who described a sort of “peace” or “quiet” that was felt. Similarly, interactions with wildlife in a natural setting had lasting influence on volunteers who would not have otherwise had such experiences. The results of this study lend support to earlier research showing that environmental citizen scientists view "getting outside" or "connecting with nature" as essential to maintaining their engagement (Domroese et al., 2017; Alender, 2017; Bruyere & Rappe, 2007). As opposed to the bulk of volunteer everyday life, environmental citizen science programs provide people the chance to be outside, which is one possible interpretation of this motivation. This association between volunteerism and the natural world is significant because it shows how individuals can benefit from the activity in ways other than only contributing to the gathering of data for science. Programs for citizen science act as a conduit for establishing relationships between people and places, fostering a sense of connection to nature while furthering scientific objectives.

Participating in the scientific process, from collecting data to sharing findings, was mentioned by a sizable proportion of Blue Thumb volunteers as a key driver. Several Blue Thumb volunteers sought a more involved role in science than merely collecting data. Volunteers were interested in how data was collected, used, and in what ways they could further investigate their own questions and hypotheses. This study discovered a link between the value of data as a motivator and duration of engagement. A significant and personally valuable temporal dataset had been produced for volunteers who had observed for several years at the same location, and they believed it was crucial to keep it going through future monitoring efforts. The results of this study are consistent with prior research, which suggests that "contributing to scientific research" is a key reason for citizen science engagement (Land-Zandstra, Agnello, & Gultekin, 2021; Tinati, Luczak-Roesch, Simperl, & Hall, 2017; Raddick et al., 2013). Because of its value to volunteers, citizen science projects should communicate the scientific outcomes achieved from the acquisition of volunteer data to further encourage participation. Finally, the inclusion of science affinity as a brand-new construct in the Haywood et al. (2020) PAT model is further supported by the significance of the scientific method and data collecting to the motivations of Blue Thumb volunteers.

The second largest barrier to volunteer motivation that was described in this study was data collection and technology. Because Blue Thumb volunteers had a vested interest in how data was being used, they also expressed concerns about the accuracy and precision of data collected using the types of equipment provided, how to publicly access the data that was available, and ease of technology. In some instances, the issue of technical ease was directly related to location: monitoring frequently takes place at the stream site, along the waterway, necessitating the transportation of equipment by Blue Thumb volunteers who then conduct analysis outdoors. Other occasions, the issue stemmed from volunteers' inability to use/understand certain technology, like in the case of volunteers who were unable to access or submit data on the program's website. Previous research has identified that constraints connected to technology that affect whether volunteers stay on a project or quit (Asingizwe et al., 2020; Martin et al., 2016). While problems with ease of technology or accuracy are more project-design related problems, they are still important considerations in the retention of motivated volunteers. Programs can work with volunteers to educate them about use of project-specific equipment and technological literacy skills that are required for participation.

Limitations

Due to the voluntary and recreational nature of Blue Thumb, the study sample size was limited to volunteers who opted to participate in the study, which may have led to sampling bias as most of the volunteers who opted to participate in this research had been involved with Blue Thumb for several years. It may be important to capture more motivations of early participants, those within their first year, to better understand the motivations of all volunteers across length of participation. Additionally, this study focused on volunteer retention: how motivations and attachments to place could be used to retain volunteers already involved in the Blue Thumb program. Future research could look at the relationship between place attachments and volunteer recruitment or level of engagement. Finally, because the study population is extremely specific, the results of this study may not be generalizable to other citizen science programs.

Conclusion

This research explores the main motivators of Blue Thumb volunteers, and the importance of the specific places they monitor. The research question investigated by this work was: how can various forms of place attachment between Blue Thumb volunteers and the sites they monitor influence motivation to continue water quality monitoring? This research used the Personal Attachment model (PAT) described in Haywood et al. (2021), to classify typologies of volunteer motivations along three dimensions: personal context, community context, and natural environmental context. Blue Thumb volunteers expressed a range of place-based motivations. Blue Thumb volunteer motivations fell within the same dimensions proposed in the PAT model. As seen in previous studies of motivation, volunteer motivation is complex and multi-faceted. Blue Thumb volunteers often have more than one primary identified reason for participating. Blue Thumb volunteers were largely motivated by personal attachments, social relationships, and connection to the environment that relied on the specific sites that they monitored.

There are now several studies that demonstrate that place-based experiences and attachments are a strong motivator of continued environmental citizen science (Halliwell, Whipple, & Bowser, 2022; Lucrezi, 2022; Seymour et al., 2022; Haywood, Parrish, & He, 2021). As demonstrated in this study, the place environmental monitoring occurs in influences several different modes of place attachment that motivate volunteers in a variety of ways. The findings of this study suggest that environmental volunteers develop attachments to places they consistently monitor, and in turn are motivated to continue engaging at specific locations due to these attachments. While this research focused on one water quality monitoring program, Blue Thumb, the implications of this study extend not only to other water monitoring projects but to other place-based volunteerism.

The first step in being able to anticipate how, when, for how long, and why a volunteer will participate in a particular citizen science project is to understand the complexity of volunteer motives. To retain and sustain volunteers, citizen science projects must understand and then deliver what motivates contributing individuals to ensure long-term engagement. Tailoring volunteer experiences to highlight individual motivations is likely key to continued success of citizen science projects. More research is needed to understand not only how volunteers are motivated by the places they monitor, but to what depth volunteers feel attachment to place and how place influences specific participant outcomes. A better understanding of what motivates volunteers, and the role of place in volunteerism, is beneficial for project managers as well as the participants themselves to ensure high levels of engagement, retention, satisfaction, and sustained participation. This interactive approach, between project managers and volunteers, will result in sustainable projects that not only contribute to biodiversity and conservation but also meaningful experiences for participants themselves.

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CHAPTER IV

CITIZEN SCIENCE PARTICIPANT SELF-EFFICACY AND SKILL: ACHIEVING OPTIMAL DATA QUALITY

Introduction

Recent years have seen a rise in the number of citizen science initiatives that include the public in ongoing scientific research. A common definition of citizen science is that it is a type of research partnership in which non-scientists from the public participate in data collection, analysis, and dissemination activities for scientific research initiatives (Conrad & Hilchey, 2011; Dickinson et al., 2012; Haklay, 2013; Wiggins & Crowston, 2011). Citizen science has a long and rich history of data gathering and public involvement in the field of environmental monitoring (Conrad & Hilchey, 2011; Pocock et al., 2017) across large scales (both spatially, and temporally) that may be otherwise unfeasible (Bonney et al., 2009; Briggs & Krasmy, 2013). Nonetheless, data gathered by volunteers is frequently subject to scientific inspection, and a great deal of study has gone into validating and confirming this data (Muenich et al., 2016; Stepenuck & Genskow, 2017). There is a gap in the literature since previous research has not looked at how learning outcomes relate to data quality or identified the critical factors that influence volunteer data gathering. The goal of this study is to compare the accuracy of data collected by volunteers for Blue Thumb, a citizen science program that monitors water quality, with their perceptions of their own capacity for scientific inquiry. An explanatory sequential mixed methods design is used, that involves collecting volunteer quality assurance data first, then explaining trends in data quality with qualitative responses and learning outcome scores.

Study Background and Context

Data Validity and Monitoring Programs

Many academics interested in the assessing the outcomes of environmental citizen science have concentrated on characterizing and evaluating the veracity and trustworthiness of data gathered by volunteers (Haywood 2014; Muenich et al., 2016; Ottinger, 2010; Peckenham et al., 2012). While monitoring data is essential for resource management, citizen collected data has often been challenged and perceived by scientists as non-credible (Conrad & Hilchey, 2011; Stepenuck & Genskow, 2017). Credibility, as it can be defined in citizen science, refers to the quality of being "believable or worthy of trust" (Freitag, Meyer, & Whiteman, 2016). There are numerous published analyses that compare data quality to demonstrate that quality citizen data is frequently comparable to expert data (Canfield et al., 2002; Muenich et al., 2016; Scott & Frost, 2017). Skepticism of citizen science data is, in part, due to a perception that citizen science programs lack adherence to the same evaluation and validation criteria that scientists adhere to (Buytaert, et al., 2014). While there are many studies that focus on the quality of volunteer collected data, there are relatively few studies that focus on what specific factors may influence the quality of collected data (Jollymore, Haines, Satterfield, & Johnson, 2017). If citizen-generated data is to be used and considered in decision-making, or influence policy, it must be seen as legitimate.

It is important to recognize that factors other than collection method can influence data quality. Participants' perceptions of skill acquisition, reasons for participation, level of engagement, and belief in one's own abilities may also have an impact on the quality of data collected (Deguines, deFlores, Lois, Julliard, & Fontaine, 2018; Tiago et al., 2017). Engaged participants contribute more observations allowing for an increase in the overall quality of a dataset (Serret et al., 2019). Other studies have shown that citizens who have increased interest, or motivations, may contribute more observations over a longer period and thus improve dataset quality (Dickinson & Bonney, 2012; Jollymore et al., 2017; Prestopnik & Crowston, 2011). Length of participation may also be a factor, as volunteers who have continued participating in a monitoring program long-term are likely to improve program specific skills and knowledge and improved skill acquisition over time as volunteers gain experience (Deguines et al.,2018; Serret et al., 2019). Two outcomes that may be related to data quality are self-efficacy and the capacity for scientific inquiry, but they have not yet been examined in current academic research.

Learning Outcomes: Self-Efficacy and Skill

Prior research has predominantly focused on measuring engagement in citizen science through output measures, such as the number of participants or the amount of data collected (Phillips et al., 2018; Phillips, Ballard, Lewenstein, & Bonney, 2019). More recently, new focus is being given to evaluating the learning outcomes of participants and beneficial outcomes for environmental volunteers, ranging from increased knowledge and awareness about environmental issues, to transferable skills, and changes in environmental behaviors and attitudes (Bonney et al., 2009). A recent framework designed by Phillips et al. (2018), classifies participant outcomes into the following categories: content, process, and nature of science knowledge, interest in science and the environment, skills, self-efficacy for science and the environment, behavior and stewardship, and motivation. Previous phases of research analyzed Blue Thumb volunteers' behaviors, motivations, and interests. The current study addresses Blue Thumb volunteer's self-efficacy and skill level in relationship to data quality.

Self-Efficacy. Self-efficacy is defined as a person's belief about their capabilities to learn specific content and to perform project-specific behaviors in citizen science (Phillips et al., 2018).

A participant's self-efficacy translates to the extent to which a learner has confidence about their abilities to participate in a scientific activity (Deci& Ryan, 1985; Hiller & Kitsantas, 2016; Phillips et al., 2018). Alender (2016) wrote that volunteer project outcomes are influenced by the quantity and quality of volunteer participation. Research shows that high self-efficacy is correlated to volunteer motivation, engagement, and retention (Zimmerman, 2013; Hiller & Kitsantas, 2016; Kao et al., 2020; Schunk & Pajares, 2005). Furthermore, in terms of data collection, studies indicate that volunteers with high self-efficacy scores contribute data more often in their respective projects (Tiago et al., 2017).

Research suggests that self-efficacy is also important to developing the necessary skills to carrying out the principal activities of a citizen science project with accuracy (Crall et al., 2011; Harp et al., 2017; Kossowska et al., 2018). Foundational studies around self-efficacy find that changes in an individual's perceived self-efficacy can influence their performance on a specific goal or task (Lent, Brown, and Hackett, 1994). Self-efficacy can be a predictor of successful acquisition of specific skills required to participate in a citizen science activity. In a study by Crall et al. (2011), volunteer success with species identification increased with the level of volunteer self-identified comfort. The quality of data collected by volunteers in citizen science monitoring programs may relate to the level of self-identified ability, with volunteers who score higher on self-efficacy scores being more likely to continue collecting data, and gaining skills related to their specific projects. The relationship between volunteers' self-efficacy and perceived skill level needs to be further studied.

Skills of Science Inquiry. In the context of this research, skills of science inquiry is considered a subset of scientific literacy that deals with volunteers gaining specific skills that are required for participation in a citizen science program (Phillips et al, 2018). The process of inquiry includes practices such as asking and answering questions, collecting data, critical thinking, developing models, experimentation, providing explanations, interpreting data, and communicating results (Stylinski et al., 2020). Many of these science-inquiry skills are expected as a natural part of participating in specific environmental-monitoring citizen science programs, due to the hands on-nature of the projects and the repeated experiences of the volunteers (Phillips et al., 2018). Being able to follow specific project protocols, gather and analyze data, identify organisms, use specific instruments, and communicate/report results are often considered the top desired skills from project administrators, as these are skills that potentially correlate to data quality (Peter et al.,2021).

Many published citizen science evaluations have shown that participation in citizen science can improve specific volunteer data collection skills (Bonney et al., 2009; Bonney et al., 2015; Aristeidou & Herodotou, 2020; Peter et al., 2021). Fewer studies attempt to analyze how scientific inquiry skills relate to data quality. Research has investigated how volunteer skill level, and ability to follow data collection protocols set by a citizen science program, influence data collection alongside volunteer retention (Balázs et al., 2021). Some studies suggest a relationship between user interface design of citizen science tools and volunteer self-efficacy, skill level, and ability to follow collection protocols (Crall et al., 2011; Bell et al., 2013; Danielsen et al., 2014). It is pivotal that any skill desired by a citizen science program is assessed rather than assumed to be gained. Research is needed to evaluate skill acquisition to further determine the role that perceived skills of science have on data quality.

Water Monitoring Program: Blue Thumb

In terms of number of programs, water quality monitoring is one of the largest categories of citizen science programs in the United States (Grudens-Schuck & Sirajuddin, 2019).

Volunteers have contributed data that has been used to assess watersheds and implement management decisions following the Clean Water Act in 1972 (Jollymore et al., 2017). Current research on water monitoring citizen science estimates that there are over 1,800 established projects and 8,500 volunteers monitoring freshwater habitats (streams, ponds, wetlands) annually worldwide (Overdevest, 2004). In recent years, the Environmental Protection Agency (EPA) has sponsored many state-led volunteer programs to encourage the collection of local water data (McKinley et al., 2017). At least twenty-six states sponsor volunteer monitoring programs (Overdevest, Orr, & Stepenuck, 2004) with many of these programs using data collected from volunteers to publish reports on water bodies that have the potential to be used for policy and resource management decisions (Metzenbaum, 2002). Citizen scientists help to collect water quality data across large spatial and temporal ranges which may be otherwise unfeasible to achieve.

In the state of Oklahoma, Blue Thumb is the educational arm of the Oklahoma Conservation Commission (OCC) Water Quality Division. This program is the primary means by which the OCC addresses the Non-Point Source Pollution Management Plan (NPSMP) objective focused on education (Blue Thumb, 2019). The mission of Blue Thumb is "stream protection through education" statewide through water quality education and a network of volunteers monitoring local Oklahoma streams. Blue Thumb volunteers collect chemical data on local streams (chloride, dissolved oxygen, nitrate/nitrogen, pH, phosphorous, and more), biological data (in the form of macroinvertebrate and fish collections), perform habitat assessments, and share their knowledge of water quality with others in their communities (Blue Thumb, 2019). Data collected by volunteers is presented publicly on the Blue Thumb website (www.bluethumbok.com). This citizen science program averages between 75-100 active sampling sites annually, over 300 active volunteers, and an average of 8,000 hours of logged volunteer time (Blue Thumb, 2019).

As a means of legitimizing data, some citizen science programs enact quality assurance measures within protocols for data collection, and review data in-house before publicizing it (Gouveia et al., 2004). Blue Thumb promotes quality assurance by requiring volunteers to collect and analyze several repeated measures (replication), follow standardized procedures (published from OCC and EPA), encouraging collaboration with experienced staff, storing data for analysis of long-term trends, and hosting bi-annual quality assurance tests for volunteers to practice data collection techniques. At quality assurance events, participants are required to sample an unknown solution (nutrient levels, dissolved oxygen levels, or another water chemistry metric that is commonly sampled as a frequent part of participation) against a known value. These quality assurance checks compare volunteer data to known data, as determined by Blue Thumb administrators. Currently, further information such as the level of confidence volunteers have in their reporting, is not evaluated. Information about how volunteers perceive their self-efficacy and skill, along with the accuracy of the data they collect, can be used by Blue Thumb to improve program training, data collection, and data quality.

Study Purpose & Research Questions

This study explores how volunteer ability and self-efficacy may affect data collection and quality. As defined previously, self-efficacy is the extent to which a learner has confidence about their abilities to participate in a scientific activity (Phillips et al., 2018). In citizen science, studies of self-efficacy often focus on perceived increases to understanding the process of science as a product of participating in a particular activity (Peter et al., 2021). However, the role of self-efficacy in volunteer skill acquisition and data quality is uncertain and lacking in the literature.

Currently, there are no studies that attempt to relate volunteer perceptions of skill acquisition with self-efficacy, or both variables with data quality. As a result, it's crucial to look into how participant outcomes—like self-efficacy and skill—affect the caliber of data generated. In order to encourage ongoing involvement and high-quality data, program administrators can then apply best practices to foster self-efficacy and skill growth inside monitoring programs. The current study asks the following research questions: 1) How does length of participation influence volunteer perceptions of self-efficacy and scientific skills? and 2) How do self-efficacy and skill level relate to data quality?

Methods

This study consisted of a combination of quantitative and qualitative data collected in a mixed methods explanatory sequential design. In this first phase of this study, participants analyzed water quality parameter data (physical data) against known values at quality assurance events to investigate volunteer accuracy, then completed a compiled self-efficacy and skill survey (quantitative data). The second phase of this study was conducted as a follow up to the quantitative results to help explain trends in volunteer scores on quality assurance tests, and self-efficacy and skill surveys. In this exploratory follow up, volunteers participated in semi-structured interviews to further investigate their perceptions of their self-efficacy and skill during quality assurance testing.

Water Quality Parameters

Quality assurance data was collected from volunteers twice in 2022-2023: once in Fall 2022, where volunteers measured chloride and temperature, then again in Spring 2023, where volunteers measured pH, nitrate, and temperature (Appendix C). At each quality assurance event, water samples were prepared to have known values by the Blue Thumb staff, then tested against by volunteers. Volunteers used Hach © kits for testing water variables. The protocol for testing has been determined by Blue Thumb's quality assurance plan. Volunteers take repeated samples and are provided with information on how to interpret results. Chloride is tested by performing a titration using silver nitrate titrant and interpretation of a color-change/amount of titrant as indicator of concentration in units of 5 mg/L. The nitrate test utilizes pre-made nitrate and nitrite testing strips. Nitrate strips are exposed to the sample, then aerated for 30 seconds and interpretated relative to a provided color chart. Nitrate results are interpreted against a color chart that range from 1 -2, 5, 10, 20, and 50 mg/L. Temperature is tested using a Blue Thumb provided metal thermometer. The thermometer is placed 15 cm below the surface of the sample and left while other quality assurance tests are performed. It is then read at the end of sampling. Lastly, pH is tested using an indicator solution to color the sample, which is then placed in a black box comparator and read against a color wheel that is interpreted by units of 0.50. Volunteer results are compared to Blue Thumb's Measurement Quality Objectives (or MQOs) that are specified in their annual quality assurance plan (Table 13; Blue Thumb, 2022).

Table 13: Measurement Quality Objectives (MQOs) to assess precision of chemical data, obtained from 2022 Blue Thumb Quality Assurance Project Plan (QAPP). Additional interpretations have been denoted with a * by the researcher.

Analyte	MQO	Action if MQO is Violated
Dissolved Oxygen	± two drops of sodium thiosulfate titrant	Discard subsamples and repeat procedure with new subsamples. If the MQO is still not met, resample.
Ammonia Nitrogen	± one color on the color cube	Discard subsamples and repeat procedure with new subsamples. If the MQO is still not met, resample.
Nitrate/nitrite	± one color on the color chart on the bottle * Units read on color chart are: 1 ppm, 2 ppm, 5 ppm, 10 ppm, 20 ppm, and 50 ppm	Test two more strips. If the MQO is not met, repeat with a new subsample. If the MQO is not met, resample.
Orthophosphate as Phosphorus	± one color on the color wheel	Discard subsamples and repeat procedure with new subsamples. If the MQO is still not met, resample.
pH	± one color on the color wheel	Discard subsamples and repeat procedure with new

	* Units read on color chart wheel increase by units of 0.50.	subsamples. If the MQO is still not met, resample.
Chloride	± two drops of silver nitrate titrant * One drop of silver nitrate titrant is equivalent to 5 mg/L on low range test	Discard subsamples and repeat procedure with new subsamples. If the MQO is still not met, resample.

Survey Design & Sampling

Only the spring 2023 participants were given surveys, as fall 2022 quality assurance events happened before the start of this research. Three modified versions of participant outcomes surveys created by Cornell Lab of Ornithology were used in the following research: the Self-Efficacy for Learning and Doing Science Scale, or SELDS ($\alpha = 0.92$, item load >0.70), the Self-Efficacy for Environmental Action Scale, or SEEA ($\alpha = 0.89$, item load >0.70), and the Skills of Science Inquiry Scale, or SSI ($\alpha = 0.912$, item load >0.50) which included both general and custom scale options (Porticella et al., 2017a; Porticella et al., 2017b; Porticella et al., 2017c). The SELDS and SEEA response items ranged from 1 ("Strongly Disagree") to 5 ("Strongly Agree") and were reported by median. Scores below 3 were interpreted as indicative of low levels of confidence in learning project-related information and/or effectively addressing environmental concerns. The SSI response items ranged from 1 ("Strongly Disagree") to 5 ("Strongly Agree") and were reported by median to interpret where most volunteers answered. For interpretation, average scores below 3 indicated low levels of skills in science inquiry specific to Blue Thumb. Modifications to surveys included, 1) additional questions to assess participants' self-efficacy concerning specific "skills" that they perform with Blue Thumb (denoted as "Custom" surveys), and 2) the changing of terminology to better fit Blue Thumb subject matter (Appendix D).

Open-ended questions at the end of each survey item were designed to probe the perceptions and voice of each volunteer (Appendix E). Additionally, follow-up interviews at the end of survey completion focused on volunteers' perceptions of their self-efficacy at quality assurance events and in the field, which skills they perform with routine monitoring that they felt most and least accurate with, and identification of any obstacles that volunteers felt impeded the collection of high-quality data. Qualitative data were intended to enhance meaning or give context to the previous quantitative survey results, and to compare volunteers' perception of self-accuracy with actual accuracy data.

Volunteers were surveyed and interviewed using criterion (purposeful) sampling methods. Inclusion criteria for volunteers included: they were 18 years or older, had successfully completed a two-day training, had begun monitoring at a stream, and were attending a quality assurance event. Volunteers who attended the quality assurance event and completed a survey, but did not complete a quality test, were excluded. Categories for volunteers were created based on length of total participation with Blue Thumb, and volunteers were assigned with the following length groups: New Volunteer (≤ 1 year), Established Volunteer (2-5 years), Seasoned Volunteer (6-9 years), or Long-Term Volunteer (9+ years). After removing surveys that did not meet the previously identified criterion, 26 volunteers completed both a survey and interview, while a total of 82 quality assurance tests were completed.

Data Analysis

Relationship between length of participation, self-efficacy, and skill level. Quantitative results were analyzed using SPSS software to produce descriptive statistics of scores on the SELDS and SSI survey items. Descriptive statistics were calculated for the following survey items: Blue Thumb skill level, skills of science inquiry, self-efficacy for learning and doing citizen science, and self-efficacy for environmental action. Boxplots of survey data were created to visualize the differences in scores between volunteers based on length of participation between new, experienced, seasoned, and long-term volunteers. Kruskal Wallis H test analyses were performed between survey responses across length groups to determine if there were significant differences in survey scores based on length of participation

Validity of volunteer data. In Fall of 2022, tests for chloride and temperature were conducted. In Spring of 2023, tests for pH, nitrate, and temperature were conducted. Descriptive statistics of collected water quality data were analyzed using SPSS. Mean absolute error (MAE) was calculated on the quality assurance data to compare the magnitude of difference between the water quality parameter observations of new, established, seasoned, and long-term volunteers to the true (known) values. Next, Spearman Rank Correlation analyses were used to determine if there were statistically significant correlations between water quality parameters based on length of participation, level of self-efficacy, or level of skill.

Qualitative analysis. Data analysis was performed according to Braun and Clarke (2006) thematic analysis procedures. The researcher conducted and recorded interviews, wrote and reviewed memos across the interview process, and transcribed interviews by hand. Interviews were transcribed and coded using QDA Miner software (QDA Miner 4.0, 2015; Linneberg & Korsgaard, 2019). Codes were sorted into categories of data quality, self-efficacy, and skill. Analysis of qualitative interview data focused on identifying how participants perceive their level of confidence and skill acquisition as it pertains to project-specific activities that volunteers are expected to complete. The last step of data analysis involved integration of quantitative and qualitative data. Integration involves combining both types of data to develop results and interpretations that expand on the total understanding of results and provide more comprehensive information (Creswell et al., 2011). Qualitative answers were used to explore any differences in quantitative data between groups of participants (Creswell et al., 2011).

Results

Demographic Summary

Demographic data of the categorical volunteer groups is provided below (Table 14-15). Demographic information across both volunteer groups was similar. Female volunteers were more predominate than male volunteers (61%/65% female to 35%/39% male). Volunteers were sorted into different "experience groups" based on the years they indicated that they participated in Blue Thumb: new, established, seasoned, and long-term. Both volunteer groups had similar length of participation spread between the four categories. Additional information was collected from the Spring 2023 sample, and included age, level of education, and career. This information revealed that many Blue Thumb volunteers at quality assurance events are middle-aged females, with higher levels of education, and largely scientific backgrounds. This data matches previously phases of evaluation on Blue Thumb demographics.

Table 14: Sex and years in Blue thumb between Fall 2022 and Spring 2023 quality assurance events.

Demographic	Fall 2022	Spring 2023
Sex		

Female	24	9
Male	37	17
Years in Blue Thumb		
New (<= 1 year)	12	8
Established (>1 - 5 years)	21	7
Seasoned (>5 - 9 years)	16	8
Long Term (>9 years)	16	3

Table 15: Additional demographic data of Blue Thumb volunteers at Spring 2022 quality assurance events.

Demographic	**Sample**
Age	
>=24	2
25 to 39	10
40 to 60	7
60+	7
Education	
Some College	5
Associates	1
Bachelors	9
Masters	9
Doctorate	2
Career	
College Professor	2
College Student	2
Government Employee	4
Group/Other	4

K-12 Teacher	5
Landowner	3
Scientist	6

Self-Efficacy and Skill Level

The first part of analysis focused on determining if there was a relationship between length of participation and volunteer perceived self-efficacy and skill level. Across all scales, a few trend generalizations can be made: 1) volunteers with a longer history of participation in Blue Thumb tended to perceive their skill and self-efficacy higher than those who were new to the program, and 2) volunteers who were new to Blue Thumb had more variation in responses than more experienced volunteers. However, a Kruskal Wallis H test showed that there was no statistically significant difference in perceived skill or self-efficacy levels between the different volunteer length groups (Table 16, $p>0.05$ for all survey items). Each of the scales is explored in more detail below.

Table 16: Kruskal Wallis H test results for self-efficacy and skill based on length of participation.

Scale Item	Df	H	P
Blue Thumb Skill	3.00	3.04	0.69
Science Skill	3.00	0.61	0.89
Citizen Science Self-Efficacy	3.00	3.29	0.35
Environmental Self-Efficacy	3.00	3.54	0.32

The SSI (custom) asked volunteers' perception about having the skills necessary to complete Blue Thumb specific tasks, from making observations to collecting data in a standardized manner (Phillips et al., 2017; Appendix B). A Kruskal Wallis test revealed no significant different in survey responses between questions based on volunteer length groups, indicating that new and experienced volunteers shared similar perceptions about their ability to complete Blue Thumb tasks (Figure 10). Volunteers were more confident at basic monitoring skills, such as collecting and submitting data, understanding data collection protocols, and making observations/recording data. However, volunteers were less confident in more science-inquiry skills such as designing a study, conducting statistical analyses, or interpreting data.

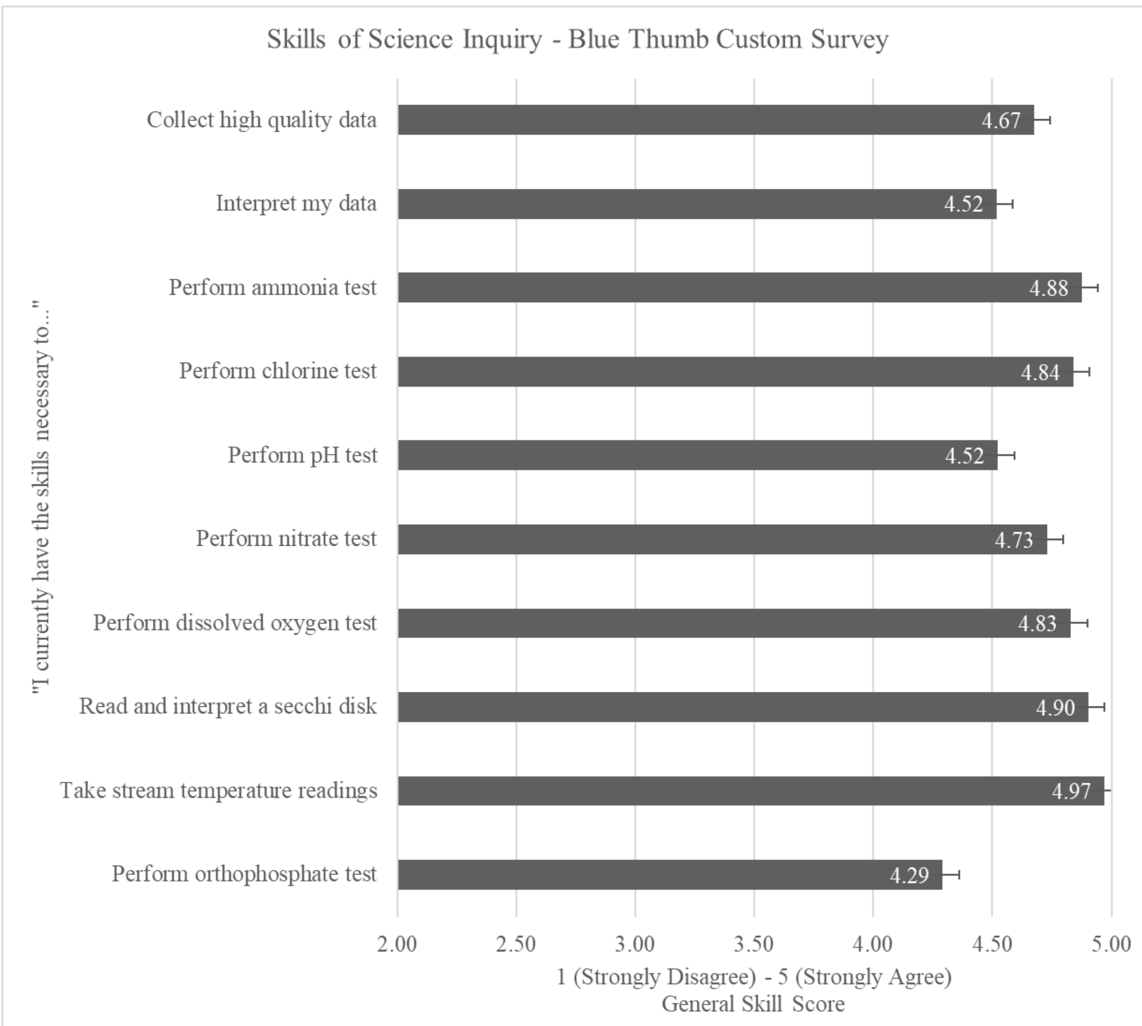

Figure 10: Skills of Science Inquiry (custom) survey items response scores.

The general SSI asked volunteers whether they perceived that they had the skills necessary for science inquiry, contextualized for water quality testing (Phillips et al., 2017; Appendix B). All volunteer groups reported high levels of perceived skill in Blue Thumb specific skills (Figure 11). A Kruskal Wallis test revealed no significant different in survey responses between questions based on volunteer length groups. All volunteers reported high confidence in water quality monitoring specific skills and tests that are a part of the Blue Thumb program.

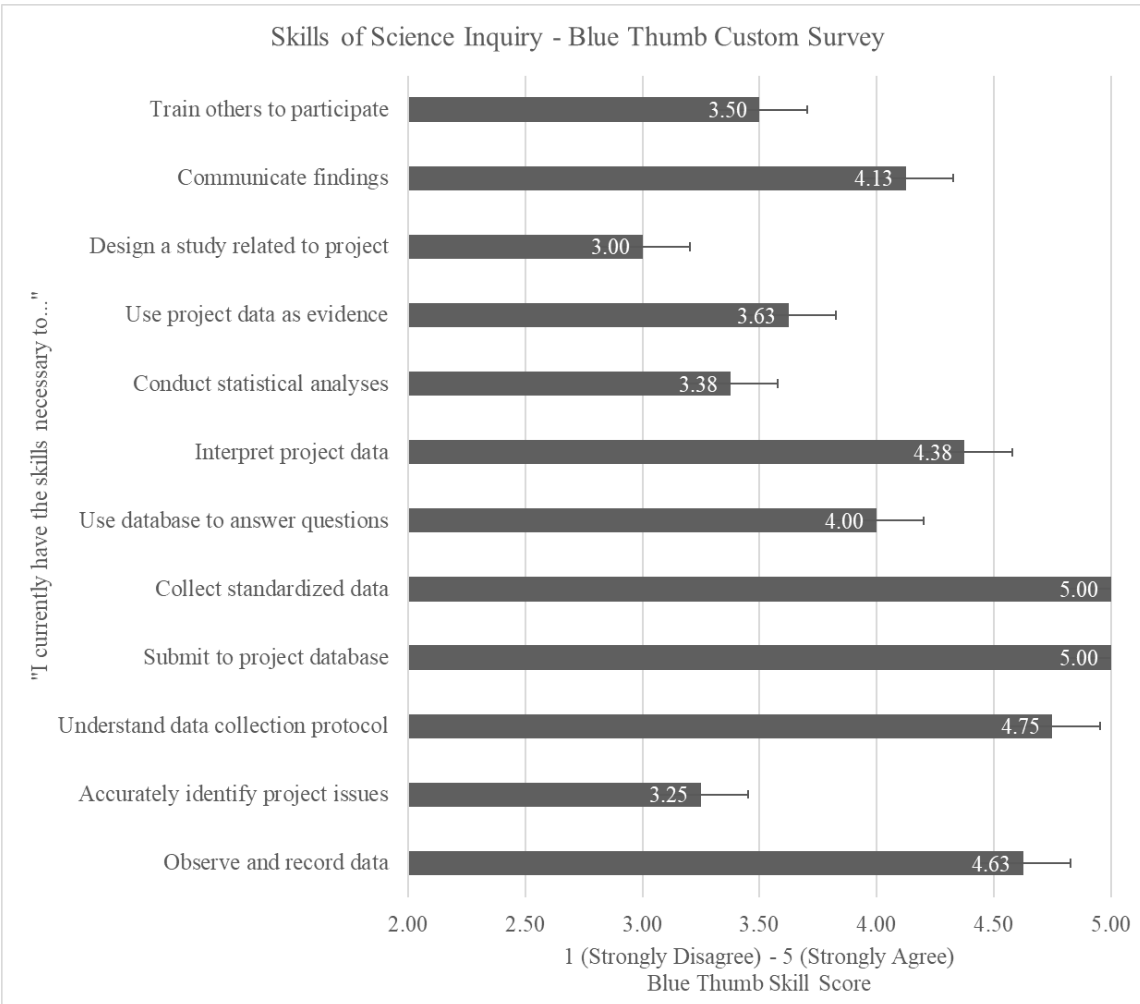

Figure 11: Skills of Science Inquiry (general) survey items response scores.

The SELDS scale asked about volunteers' self-efficacy for learning and doing citizen science (Phillips et al., 2017; Appendix B). All volunteer groups reported high levels of self-efficacy for citizen science specific activities (Figure 12). A Kruskal Wallis test revealed a significant difference in volunteer response to the prompt "It takes me a long time to understand new water quality topics" and "I can explain water quality to others". New volunteers indicated that it takes them a longer time to understand new topics, while more experienced volunteers indicated that it takes them a significantly less amount of time. Whereas experienced volunteers were more likely to indicate higher ability to explain water quality to others. Overall, combined volunteer responses indicate higher self-efficacy in "doing" citizen science (such as following instructions, or monitoring) and less self-efficacy in "learning" citizen science (such as understanding topics related to their projects).

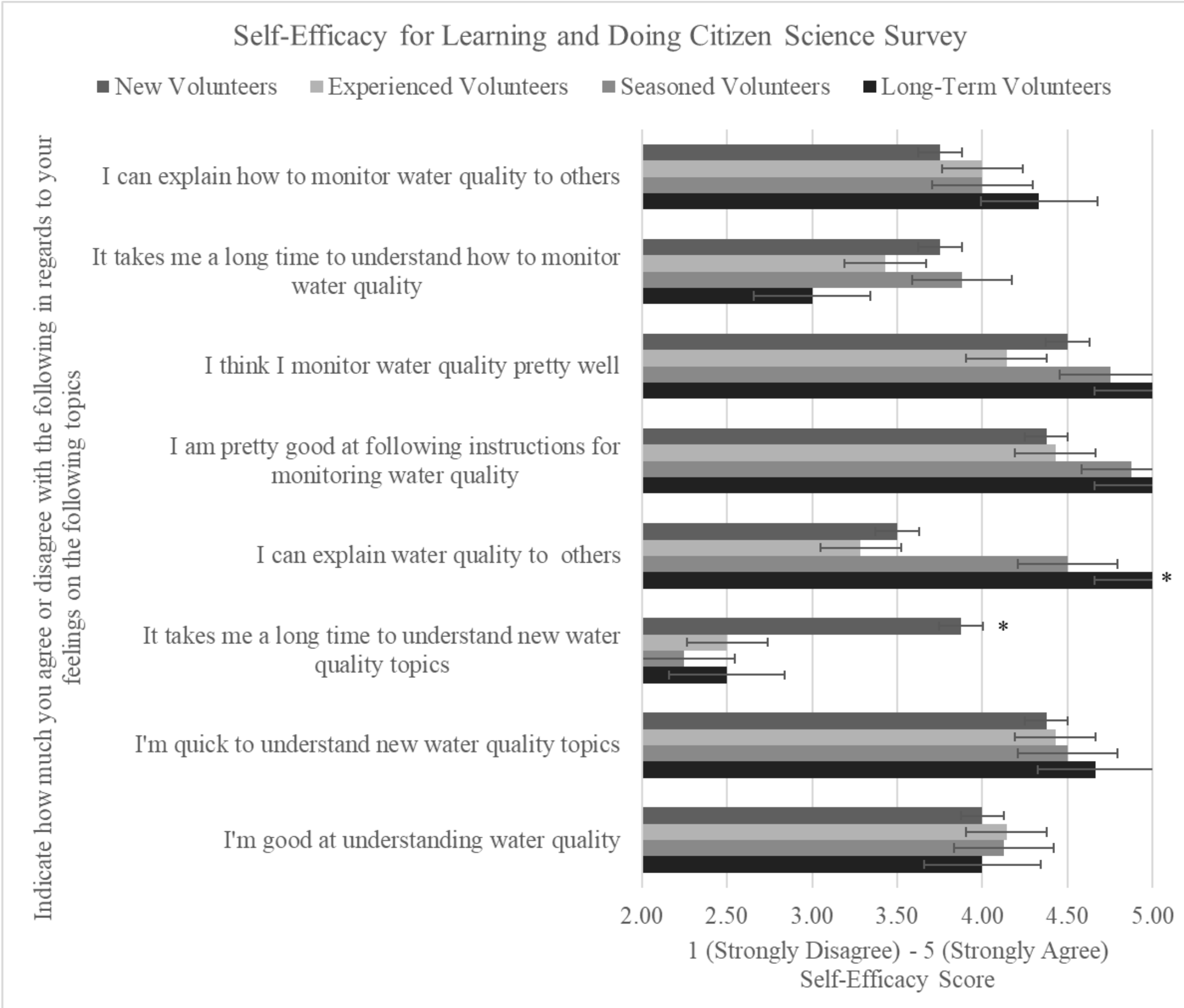

Figure 12: Comparison of Self-Efficacy for Learning and Doing Citizen Science survey items response scores across volunteer length groups: New (<= 1 year), Experienced (>1-5 years), Seasoned (>5-9 years), and Long-term (>9+ years). An asterisk (*) denotes significant differences.

The SEEA scale asked about volunteers' self-efficacy for environmental action (Porticella et al., 2017c; Appendix B). A Kruskal Wallis test revealed no significant different in survey responses between questions based on volunteer length groups (Figure 13). Volunteers reported high levels of self-efficacy for environmental action to protect and improve local water quality issues. Volunteers disagreed with prompts such as “I don’t think I can make a difference in water quality issues” or “It’s hard for me to imagine myself helping protect local streams”.

Figure 13: Self-Efficacy Environmental Action survey items response scores.

Semi-structured interview data was analyzed in conjunction to the quantitative findings. First, volunteers were asked to describe the skills that they had gained through their participation, and reasons why they felt they had achieved that skill. Volunteers generated categories of skills of science inquiry such as: making observations, noting trends in data, following collection protocols, repeatability in testing, and analyzing data. All volunteer responses indicated high levels of perceived skills gained in Blue Thumb specific tasks, such as collecting water quality data. Many volunteers attributed their high perceived skill scores as being due to the "thorough training provided by Blue Thumb as a requirement to participate". While survey scores for general scientific skills were somewhat lower, this may be explained by volunteers who did not consider themselves to be "from a science background", as seen in this volunteer,

> I trust my skill level, but I'm maybe mediocre at some things. I'm not a scientist (…) so I maybe am not as meticulous as I could be. I'd rate my skill level at like 75% compared to a scientist.

Next, volunteers were asked to describe their confidence level in each of the required quality assurance tests outlined in Figure 13. Responses were coded as either "confident" or "unconfident", to compare how volunteers felt about different tests. Responses indicated that volunteers felt more comfortable with certain tests (like temperature, and secchi disk readings) as compared to others (like orthophosphate). Some reasoning provided for confidence in certain tests included, a) the tests were quantitative and had exact numbers or values, and b) the process involved in interpreting the data was more straightforward or included less steps. Reasoning for unconfident responses included, a) ome of the tests used in quality assurance were tests that volunteer rarely saw results for in the field, and b) the tests were more qualitative in nature and relied on volunteer interpretation of variables like colors. As one volunteer stated,

> It is difficult to see color change on [these tests]. And typically, when we monitor, we never see large amounts. Small amounts with slight color changes are hard. When I'm holding that instrument up to the light and turning the color wheel, it's hard to determine what I'm actually seeing.

Quality Assurance Data

The second part of analysis focused on determining if there was a relationship between length of participation, self-efficacy, skill, and the accuracy or quality of volunteer reported water data. First, descriptive statistics were calculated for all water quality parameters tested at Blue Thumb quality assurance events (Table 17). Second, percentage agreement of participant measured values within acceptable ranges was determined using the Blue Thumb's 2022 quality assurance project plan (Table 18). Finally, a Kruskal Wallis H test was conducted for water quality assurance data based on length of participation. (Table 19). Each water quality parameter test is discussed in detail below.

Table 17: Descriptive statistics and mean average error (MAE) of water quality parameters tested by Blue Thumb volunteers between Fall 2022 (n =61) and Spring 2023 (n =26) based on length of participation: New ("N", <= 1 year), Established ("E", >1 - 5 years), Seasoned ("S", >5 - 9 years), and Long Term ("L", >9 years). Known values for each variable were: chloride = 30mg/L, pH = 6.00, nitrate = 15mg/L, and temperature = 0°C.

Parameter	Level	N	Mean	Std. Deviation	Mean Average Error
Chloride (mg/L)	N	12	36.25	3.11	6.25
	E	21	34.29	3.27	4.29
	S	12	35.42	2.58	5.42
	L	16	33.75	3.87	3.75
pH	N	8	5.76	0.24	0.24
	E	7	5.60	0.19	0.40
	S	8	5.68	0.24	0.36
	L	3	5.78	0.25	0.20
Nitrate (mg/L)	N	8	16.88	3.70	3.13
	E	7	15.14	5.01	4.43
	S	8	18.75	2.67	3.57
	L	3	14	5.29	4.50
Temperature (C)	N	8	0.5	0.76	0.90

E	6	0.00	0.00	0.00
S	8	0.38	0.74	0.29
L	60	0.43	0.87	0.30

Table 18: Percentage agreement of participant measured values within acceptable ranges determined in Blue Thumb's 2022 quality assurance project plan. Temperature did not have an established acceptable value, so 1 degree of difference was used for comparison.

Experience Level	Chloride 30 ± 5 mg/L	pH 6 ± .05	Nitrate 20 ± 1 mg/L	Temp 0 ± 1 °C
New (<= 1 year)	67%	100%	100%	87%
Established (>1 - 5 years)	86%	100%	100%	100%
Seasoned (>5 - 9 years)	83%	100%	100%	94%
Long Term (>9 years)	81%	100%	100%	75%

Table 19: Kruskal Wallis H test results for water quality assurance data based on length of participation.

Parameter	df	H	P
Chloride	3.00	6.60	0.086
pH	3.00	4.67	0.200
Nitrate	3.00	3.61	0.310
Temperature	3.00	14.48	0.002

Chloride was tested at both Fall 2022 Blue Thumb quality assurance events and had a large amount of participant data submitted (n=61). The known vale of chloride in the sample prepared by Blue Thumb for quality assurance testing was 30 mg/L. Volunteers, regardless of length of participation, had an average score that was near 35 mg/L with some amount of deviation in responses. No statistically significant difference was found in the reported chloride concentration between volunteers of different length categories (p = 0.086, Table 17). However, new volunteers overestimated the amount of chloride by 6.25 mg/L, which goes beyond the accepted deviation of ± 5 mg/L, compared to long-term volunteers who overestimated to a lesser degree, or 3.75 mg/L (Table 17-18). Experienced, seasoned, and long-term volunteer groups reported chloride measurements within Blue Thumb's accepted range >80% of the time.

pH was tested only at Spring 2023 Blue Thumb quality assurance events (n=26). The known concentration of pH in the sample prepared by Blue Thumb for quality assurance testing was 6.00. All volunteers, regardless of length of participation, underestimated the pH concentration of the water sample. No statistically significant difference was found in the reported pH concentration between volunteers of different length categories ($p = 0.20$, Table 17). New volunteers and long-term volunteers underestimated the pH concentration by 0.24 and 0.20 respectively, while experienced and seasoned volunteers underestimated by 0.40 and 0.36 on average (Table 17-18). All these values fall within Blue Thumb's accepted deviation of ± .05.

Nitrate was also tested only at Spring 2023 Blue Thumb quality assurance events (n=26). The known value of nitrate in the sample prepared by Blue Thumb for quality assurance testing was 15.00 mg/L. On average, new, experienced, and seasoned volunteers overestimated the concentration of nitrate (between 3.13 – 4.43 mg/L) while long-term volunteers underestimated the concentration of nitrate (4.50 on average) present in the water sample (Table 17). No statistically significant difference was found in the reported nitrate concentration between volunteers of different length categories ($p = 0.31$, Table 19). Experienced and long-term volunteers had the highest amounts of deviation in volunteer reported concentrations (5.01 and 5.29 respectively) while new and seasoned volunteers had lower deviations (Table 16). All these values fall within Blue Thumb's accepted range of ± 1 mg/L (Table 16).

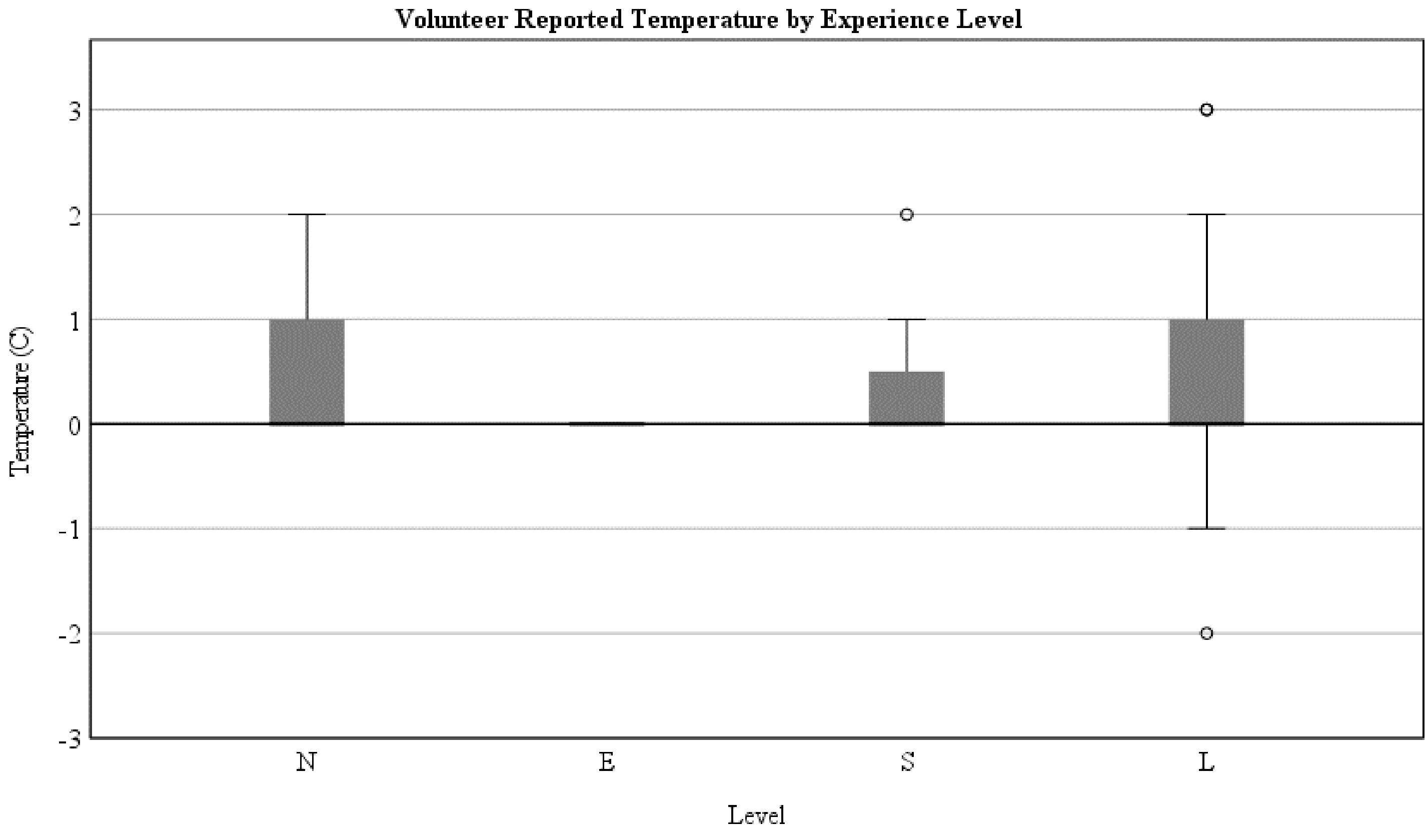

Figure 14: Boxplot of volunteer reported temperature levels at quality assurance events across volunteer length groups: New ("N", <= 1 year), Experienced ("E", >1-5 years), Seasoned ("S", >5-9 years), and Long-term ("L", >9+ years). The solid black line represents the true, or "known", value of the prepared sample. Kruskal-Wallis H = 14.48 (df = 3), $P = 0.002$.

The last tested water quality parameter was temperature, which was tested at both Fall 2022 and Spring 2023 Blue Thumb quality assurance events and had the highest amount of volunteer participation (n=82). The known temperature in the sample prepared by Blue Thumb for quality assurance testing was 0°C as indicated by the solid line in Figure 14. All volunteers, regardless of length of participation, averaged responses close to the known value. Statistically significant differences were found in the reported temperature values between volunteers of different length categories (p = 0.002, Table 19). Post-hoc Mann-Whitney tests were used to compare all pairs of groups. All length groups were significantly different when compared to the experienced volunteer category. Notably, experienced volunteers averaged the correct measured temperature of 0°C, while all other categories of volunteers had some degree of overestimation (Table 17-18). Blue Thumb did not have an acceptable range of response, so a degree of ± 1 °C was tested (Table 19). Long-term volunteers measured values within this accepted range the lowest, at 75% of the time.

Table 20: Spearman rank correlation test results for water quality assurance data based on self-efficacy and skill survey responses for Spring 2023 participants (n = 26). Bolded values represent significant correlations (p<0.05).

Survey	Item	Quality Assurance Test	Correlation coefficient	p
Blue Thumb Skill	**Collect high quality data**	**Nitrate**	**-0.39**	**0.05**
		pH	0.11	0.61
		Temperature	0.01	0.97
	Perform nitrate test	Nitrate	-0.37	0.06
	Perform pH test	pH	-0.23	0.25
	Perform temperature test	**Temperature**	**0.40**	**0.04**
Science Skill	Observe and record data	Nitrate	-0.09	0.67
		pH	0.07	0.74
		Temperature	-0.20	0.32
	Collect standardized data	Nitrate	0.02	0.92

		pH	0.01	0.96
		Temperature	-0.11	0.60
		Nitrate	0.02	0.94
	Follow instructions	pH	0.03	0.89
Self-Efficacy		Temperature	0.23	0.25
		Nitrate	0.16	0.45
		pH	0.03	0.89
	Monitor water quality	Temperature	-0.13	0.62

To analyze the effect of skill and self-efficacy level on reported water quality parameters, a Spearman Rank-Order Correlation test was used to compare select survey responses to MAE (Table 19). In many cases, no significant relationship was found between how volunteers ranked their abilities on the skills or self-efficacy surveys and the amount of error made during their quality assurance testing (Table 19). However, three notable relationships were found between volunteers self-perceived skill in Blue Thumb monitoring and their quality assurance data. A moderate negative relationship was found between how volunteers ranked their ability to collect high quality data and the amount of error they had when measuring nitrate ($r_{s(}24) = -0.39$, $p = 0.051$), indicating that as volunteer confidence in data collection increased their amount of overall error decreased. Similarly, a moderate negative correlation was found between how volunteers ranked their ability to perform the nitrate test on the skills survey, and the amount of error they had when measuring nitrate for quality assurance testing ($r_{s(}24) = -0.37$, $p = 0.063$), revealing that volunteers were high confidence in nitrate testing were also the most accurate. Conversely, a strong positive relationship was found between how volunteers ranked their ability to perform the temperature test on the skills survey, and the amount of error they had when measuring temperature for quality assurance testing ($r_{s}(24) = 0.40$, $p = 0.04$), which indicated that as volunteer confidence in temperature increased the amount of overall error in temperature measurements also increased.

To further examine any relationship between self-efficacy and data, qualitative responses during open ended questions as a part of survey items assessed how confident volunteers were in the quality of data that all volunteers across Blue Thumb submit on their monitoring sites. Most volunteer responses were coded as "fairly – very confident", with >65% of responses (Table 21). Volunteers attributed their high confidence with receiving help and guidance from Blue Thumb staff. Many volunteers described how Blue Thumb provided resources, such as online videos or instructional PDFs, that volunteers could use both in the field and at testing events to help them follow protocols. One volunteer noted,

> I feel very confident in my own data, due to the level of supervision that we get from the program. Blue Thumb actually comes to my site and helps show me what good sampling techniques look like. The training was also really good. And we have times like this quality assurance event where we can meet to discuss our samples and stuff. Blue Thumb reaches out if something in the data looks weird, so I know they look at the quality of what I submit.

Table 21: Qualitative responses and coding frequency for the question: "how confident are you overall that Blue Thumb volunteers collect high quality and accurate data?".

Responses	N	%	Reasoning

Very Confident	4.00	15%	*"Very confident in the level of supervision from the program over volunteers. Everyone does quality assurance sessions, and Blue Thumb also checks the data that is submitted"*
Fairly Confident	10.00	38%	*"I'm somewhat confident. It's probably as accurate as it can be, considering that it's a field test with no specialized equipment and that we are human beings who may make an occasional error. But I think it's good enough"*
Confident	5.00	19%	*"I'm confident that' it's probably accurate. But some of the tests are ambiguous and hard to interpret, so I'm not super confident that it's always accurate"*
Unsure	4.00	15%	*"It depends on a lot. There's always variation between volunteer skill level, accuracy, and repetition. So I think it changes from person to person"*
Unconfident	2.00	8%	*"I don't know too many other volunteers but if I had to guess, I would think unless they have a basic understanding of chemistry then they might struggle to get accurate data"*
Very Unconfident	1.00	4%	*"I think without a background in science that maybe people don't follow the process of science and use good methods like repeatability"*

To improve volunteer self-efficacy in collected data, volunteers were asked what additional resources they thought would help improve their confident in Blue Thumb's overall data quality (Table 22). Responses from the semi-structured interviews were coded into the following categories: data availability and usage, additional training/supervision, instrumentation, and extra sampling opportunities. For data availability and usage, volunteers wanted to see more information from data collected across all Blue Thumb volunteers- from demographic data of the volunteers to statistics and deviation of reported water quality parameters. Similarly, volunteers indicated that they would like additional training or supervision to help improve their own self-efficacy when collecting data. Volunteers especially wanted more training on monitoring that was not performed on a routine monthly basis, such as the bi-annual macroinvertebrate collections.

Instrumentation was a common theme in over one-fourth of the semi-structured interviews (27%). Volunteers questioned the accuracy of some data based on the type of instrumentation or equipment that was used, especially when the equipment had subjective interpretations (like a color value). Several participants used terminology such as “individualized”, “difficult to interpret”, “biased”, and “easy to get wrong” when describing specific tests (notably orthophosphate, pH, and ammonia). Lastly, a few volunteers mentioned that sampling more than the required once a month might help to build familiarity with consistent sampling techniques and the program collection protocols. Lastly, some volunteers described how accessibility issues at their site prevented them from getting consistent data, which may lead to inaccuracies in long-term monitoring. Volunteers described how sampling only once a month made memorizing the protocols and process of interpreting data difficult.

Table 22: Qualitative responses and coding frequency for the question: “what would help you feel more confident in Blue Thumb’s overall data quality?”.

Responses	**Example Quotes**	**% Respons e**
Data Availability and Usage	*"I would like to actually see the data used in a report or some statistics on it that show the variance and accuracy"* *"I would like to see the demographics of who collects data"* *"I think the data is good enough for environmental studies. We actually send our data to the city storm water manager and they use it in a report. I'd like to see more information from our data"*	35%
Additional Training or Supervision	*"I feel most confident when another person collects and does tests with me, so I wouldn't mind more supervision from Blue Thumb. I like when they supervise during quality assurance sessions"* *"Some additional training on certain parameters. Like bacteria, which is new. I have no idea how that is actually analyzed. Or even more in-depth on the things we already do"*	31%

	"I would love more training on macroinvertebrate and fish identification. We assist in collecting these things, and even picking the bug samples, but we don't know much about them"	
Instrumentation	*"I would be interested in different types of equipment and instrumentation. I know they have probes that can do some of the laboratory work. Those are probably more accurate than the field kits we use"* *"I don't know if there's a budget or a friendly solution, but updated or standardized testing equipment would make me feel like our data is more 'scientific'"* *"Tests like phosphate that use a color wheel - I don't trust them. It's difficult to see any real change, and it's hard. I don't think it's a reliable test"*	27%
Extra Sampling Opportunities	*"For me, because I only test once every 30 days, I don't feel very accurate and my ability to recall how to do the testing isn't very strong. Maybe more opportunities to sample"* *"I'm located far away from sampling events and opportunities that Blue Thumb posts about so I don't get to participate and practice"* *"I don't get to participate in a lot of the extra events Blue Thumb has because of where I am located in the state"*	7%

Discussion

This research employed a mixed methods sequential design to answer the following research questions: 1) How does length of participation influence volunteer perceptions of self-efficacy and scientific skills? and 2) How do self-efficacy and skill level relate to data quality? In contrast to expectations, there was no statistically significant difference found between volunteers reported water parameter test data (excluding temperature) based on either length of participation or scores on self-efficacy and skill surveys. Blue Thumb volunteers reported high perceptions of self-efficacy, both for doing citizen science and environmental action, and skill, in Blue Thumb specific tasks and general science inquiry actions. Qualitative responses revealed that perceived skill and self-efficacy did vary depending upon specific Blue Thumb water monitoring tests. Data reported by Blue Thumb volunteers at quality assurance events was often near the known, prepared value. Volunteers generally performed accurate tests that fell without Blue Thumb's acceptable limits and were highly confident in their abilities. Some significant relationships between how volunteers perceived their ability to do specific tests/collect accurate measurements during QA events were found, indicating a possible relationship between volunteer perception and accuracy. This study adds to previous studies that have analyzed the accuracy of volunteer data, while exploring new factors that may influence accuracy such as self-efficacy or skill level.

Self-Efficacy and Skill Level

The study's predicted findings were that longer-term citizen science volunteers would also regard their self-efficacy and skill as being higher since they would develop these two outcomes through their continuing experience. As discovered in previous environmental monitoring research, volunteers often increase their confidence over time, with repeated monitoring experiences (Finn et al., 2010; Lewanowski et al., 2017). The analysis of survey data in this study, however, did not find any statistically significant differences in volunteer self-efficacy or skill survey results according to the duration of participation. One interpretation of the quantitative data is that these survey items were not sensitive enough for this audience that was very context specific. The impacts of participation on self-efficacy and skill may be unique to each volunteer, and therefore a scaled survey instrument alone may not be enough to show impacts to individuals. Another possible interpretation is that volunteers who choose to participate in quality assurance events, and voluntary surveys, are self-selected or those who are more likely to have pre-existing high levels of self-efficacy – as seen in previous participant outcome evaluation research (Lynch et al., 2018).

As seen in previous research, length of participation was less likely to increase self-efficacy or skills related to the process of general science inquiry as compared to self-efficacy or skills related to project specific tasks (Jordan et al., 2011; Heiss et al., 2021). This could be because participation in Blue Thumb mostly focuses largely on data collecting, which is a minor aspect of the scientific method, hence only enhancing self-efficacy and proficiency in project-specific activities. A lack of understanding of scientific processes limits volunteers' ability to engage in decision-making, or to answer questions to scientific problems (Yacoubian et al., 2018). This finding highlights the importance of citizen science programs educating volunteers in the process of scientific inquiry, so that participants understand how project specific tasks align with the process of science (Jordan et al., 2011; Phillips et al., 2018).

An important finding of this mixed-methods study was that qualitative responses did not match survey items and revealed that volunteer perceptions of self-efficacy did vary based on specific Blue Thumb protocols and tests. Volunteers were less confident with their data and skill of interpretation with qualitative or subjective instrumentation, such as a color change used to interpret chloride or pH levels. Volunteers attributed their overall high survey scores to thorough training, repeated sampling experiences, and the opportunity to practice with Blue Thumb. This shows that by providing constant feedback and quality control checks, citizen science projects may enhance volunteers' perceptions of their own efficacy and skill. Providing volunteers ample opportunity to practice and hone project specific skills may lead to longer retention, and more data collection (Phillips, 2017; Edelson et al., 2018; Meschini et al., 2021). The implications of these findings for evaluation show that it may be challenging to fully capture volunteers' perceptions of self-efficacy and skill level using only quantitative survey items because they are complicated and frequently task- or project-specific.

Data Accuracy

It was anticipated that all measurements made by Blue Thumb volunteers for the purposes of quality assurance testing would be precise and have minimal error. There was no significant difference detected in water quality values for chloride, nitrate, or pH. The only test which had significant differences between volunteer length groups was temperature. In many cases, long term volunteers had about the same amount of deviation in responses as new volunteers. In general, volunteers slightly overestimated or under-estimated the true value of certain water quality parameters. Similar to earlier studies, these findings indicate some degree of over- or under-estimation of citizen science volunteers in relation to the project's unique protocols and individual characteristics, such as experience level (Hurlbert et al., 2019; Soul et al., 2019; Leocadio et al., 2021; Wood et al., 2021). Blue Thumb volunteer quality of data varied minorly with monitoring specific tasks or tests but was overall accurate. Comparing the results found in this study with the MQOs published within Blue Thumb's quality assurance project plan shows that Blue Thumb volunteers measure water quality variables within the accepted range of variability (Table 12; Blue Thumb, 2022) suggesting that volunteer data can be a reliable source for researchers with consideration to variability.

Moderate to strong correlations were found between how volunteers perceived their skill level and their amount of error during specific tests such as nitrate and temperature. Relationships in perception and accuracy were negative for nitrate, indicating that when volunteers expressed higher confidence in their nitrate testing skills, they had less error. This may relate to previous research which suggests that as projects support or increase volunteer self-efficacy it may lead to improved collection and interpretation procedures (Lynch et al, 2018). However, a strong positive correlation was found between how volunteers perceived their skill level and the amount of error during temperature measurements. That is, volunteers with the highest self-efficacy for measuring temperature had the most error in their actual measurements. Though temperature measurement variation cannot be fully explained in this study, a possible hypothesis is that volunteers felt confident in measuring temperature, because they perceived it to be “easy” (as indicated by interview responses), and therefore overestimated their ability. This was explored in the data, as long-term volunteers (with the most theoretical experience) were the those with the highest perceived self-efficacy and skill ratings for temperature, but also those with the highest amount of deviation in measured temperature values.

Qualitative responses had mixed correlation to accuracy in data quality. Nitrates were one of the tests volunteers frequently described as difficult and subjective due to color changes, and similarly volunteer measurements of this variable were more likely to have variation. However, some high scale responses on survey items were not congruent with the volunteers’ own perceptions and words. Volunteers were very confident about their temperature measurements during interview and survey items, and yet had high amounts of error on this test. This finding indicates the importance of mixed methodology in evaluation for complex factors such as volunteers’ perception of self-efficacy and skill. Quantitative findings alone may not capture the intricate nature of these personal variables and how they are perceived by volunteers (Phillips, 2017; Phillips et al., 2018).

Qualitative responses additionally allowed volunteers to indicate how they could be more confident in their data, in both collection and quality. A key finding of the study was that volunteer self-efficacy and skill was influenced not only by the program and the volunteers’ experiences, but also by the equipment and testing protocol that was being used. Participants expressed lower levels of trust in assessments thought to be more "subjective" and requiring volunteer interpretation, while expressing higher levels of confidence in assessments that relied on more "scientific" or "objective" tools. This matches a study which showed that some volunteers did not trust groundwater data generated by testing kits due to their familiarity with the limitations of the equipment (Thorton and Leahy, 2012). Many of the Blue Thumb volunteers who questioned the legitimacy of this equipment were also those who had an educational background or career related to science. Therefore, one explanation may be that self-efficacy and confidence in data is related to individuals' knowledge of the scientific process, and knowledge of expected water quality results (Thorton & Leahy, 2012). Citizen science programs like Blue Thumb may need to further consider user interface design in data collection tools, or further education about tool use and interpretation, to enable higher confidence amongst volunteers. The results of this study highlight a need to further research how volunteers' self-efficacy and data quality are influenced by the equipment used in citizen science monitoring.

Limitations of the Study

First, in this study and other studies that compare citizen science data – professional data or interpretation are held as the standard for accuracy. In this study, the known values of solutions were prepared by Blue Thumb staff directly. There exists the possibility of variation in "known" values, even when prepared by professionals. In terms of prepared solutions, another possibility in variation exists due to the equipment used for testing. It was noted during quality assurance testing that volunteer had different batches of reagents used for testing chloride. In some cases, one batch over-estimated while the second batch under-estimated chloride concentrations. Future study on this should seek to use standardized equipment as consistently as possible to ensure comparable results with minimal variation.

The statistical tests used in this study were influenced by the relative sample size: in some tested parameters this was small (<26) and in other cases it was large (>80) making interpretation and detection of differences variable between tests. Sizes of volunteer length-groups varied: there were more new volunteers with less than a year of experience who participated in QA, while there were notably less volunteers in the "long-term" category, making comparisons difficult. Secondarily, only the Spring 2022 volunteer group was given the self-efficacy and skill survey, with follow up interviews, making the amount of qualitative data used in this study more limited than the quantitative data.

There was not access to a random sample group for comparison to the volunteers of Blue Thumb. Therefore, self-selection for participation may lead to biased results, as responding to the surveys and participating in the follow up interviews was voluntary. For future studies, comparison of self-efficacy and skill of a control group (or those who have yet to participate in Blue Thumb) may reveal information about beginning perceptions of self-efficacy or skill relative to long-term volunteers.

Lastly, there was conflicting data when comparing quantitative survey responses to qualitative responses. On survey items, volunteers were more likely to indicate high perceived levels of self-efficacy and skill. However, during interviews more volunteers were likely to express some lack of confidence, and specified tests which they had difficulty performing. Future research would benefit in refining or adding additional questions to probe whether this difference is due to evaluation materials or self-selected volunteer bias.

Conclusion

This study shed light on the relationship between participant perceptions of self-efficacy and skill, which in turn influence data quality, and involvement in the Blue Thumb water monitoring program. Contrary to expectations, a comparison of volunteers' levels of participation over various time periods did not show any significant variations in perceived skill or self-efficacy. Across all levels of participation in Blue Thumb, volunteers were likely to rate their confidence in project specific tasks as high. It is possible that the lack of significantly different results is due to the voluntary and selective nature of who participates in continued citizen science: volunteers who feel confident in their ability to continue following project protocols (Crall et al., 2013). In the study of data quality, volunteer water quality measurements were very close to the known variables that were teste, with some degree of over/under-estimation. Moderate to strong correlations were found between how volunteers perceived their self-efficacy and skill, and the accuracy of the data they produced. These findings in this study suggest that there may be a relationship between volunteers' level of confidence in data collection and the measurements they report, which is important to the continued use of citizen science data.

This study is among the first to attempt to correlate volunteer self-efficacy and skill with data quality, and the findings provide insight into the relationship between volunteer perceptions and usability of citizen science data. As citizen science continues to be integral to water quality monitoring and management, examination and use of the data that is collected must be explored (Metzenbaum, 2002). It is important for citizen science programs to evaluate not only how accurate their volunteer collections are, but to assess what factors influence this accuracy. Future studies could evaluate further the perception of self-efficacy and skill among volunteers, and the relationship they have potentially have with collected data quality. As highlighted in this study, future research would benefit from the inclusion of mixed methodology – as quantitative results alone were not enough to capture the complexity of volunteers' perceptions of self-efficacy and skill and led to findings that would not have been seen in quantitative results alone.

Citizen collected data continues to be an asset for environmental monitoring and management (Bonney et al., 2009; Overdevest, 2004; Grudens-Schuck & Sirajuddin, 2019). Studies, including this one, have demonstrated that data collected by citizens is often reliable and can be used along with professionally collected data for environmental decision-making (Prestopnik & Crowston, 2011; Dickinson & Bonney, 2012). Evaluation of participant outcomes in relation to data quality is important to understand the intricate relationship that exists between individual variables and the type of data they collect (Jollymore, Haines, Satterfield, & Johnson, 2017). As demonstrated in this paper, more research is needed to accurately determine how volunteer self-efficacy influences the quality of data they collect. Future studies may attempt to correlate self-efficacy to other data quality variables such as the amount of data collected (spatially and temporally) and continued engagement of volunteers. As more methods of evaluating the reliability of citizen collected data are generated, public trust and use of this data is likely to increase as well.

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CHAPTER V

CONCLUSION

Study Overview

This dissertation evaluated a citizen science program, Blue Thumb, with the aim of understanding how volunteer experience in a place-based and data-rich program influences participant science learning, motivations, and data quality. The research used a multi-phased, mixed-methods study design to understand when, where, and how participants in Blue Thumb benefited from their volunteerism and sought to correlate specific outcomes with data quality. This dissertation's work was divided into three articles. In the first article, volunteers' actions, interests, and motives were examined to see how involvement in an environmental monitoring program affected them. The second article of the study examined the role that place-based attachments had in the motivation of volunteers. In the third article, the significance of self-efficacy and skill to the accuracy of the data in citizen science monitoring programs was examined.

Collectively, these studies address existing gaps in the literature about appropriate volunteer outcome evaluation methodology, the connection between place-based attachments and volunteer motivations in environmental monitoring, and volunteer perceptions of data quality. This research was notable because it demonstrated the necessity for mixed-methods evaluations.

Despite the lack of statistically significant quantitative findings, qualitative methods provided rich narrative and context to the survey findings. The significance of place as a primary motivation in place-based environmental monitoring programs was a prominent finding. Additionally, volunteer confidence and skill in data collection was attributed to programmatic support that provided additional experiences for volunteers to practice water quality monitoring techniques. This study is limited in terms of generalizability but benefited from being collaborative and highly context specific providing for a more in-depth evaluation. However, the results still have implications for future research, citizen science program design, and participant outcome evaluation. This final chapter summarizes the key findings for each research question, discusses theoretical and practical implications, addresses limitations, and finally makes recommendations for citizen science programs and future research.

Summary of Key Findings

Evaluating Participant Learning Outcomes

Recent advances in the field of citizen science evaluation have focused on the impacts of volunteerism on citizen science participants (Jordan et al., 2011; Merlender et al., 2016; Phillips, 2017). The field struggles with theoretical, technical, and even practical aspects of evaluating learning and participant outcomes despite widespread agreement on the significance of evaluation (Eyler et al., 2009). Many citizen science projects have lacked evaluation, have conducted less than rigorous evaluations, or conduct evaluations that do not use available theories, frameworks, or tools. This research applied an emerging framework designed by Philips et al. (2018) for evaluation of participant outcomes within a specific citizen science program.

This study asked, To what extent and in what ways does length of participation impact participants' behaviors, motivations, and interests related to water quality monitoring? Although changes in participant outcomes were positive over time, there was no statistically significant difference in behavior, interest, or motivation scores between new and experienced volunteers. The lack of statistical difference was attributed to the fact that environmental volunteering is self-selective. Volunteers begin the program with pro-environmental behaviors, and high levels of interest and motivation. This explanation was confirmed by volunteer qualitative responses, as many indicated that their levels of behavior, interest, and motivation had always been relatively the same – and these factors drove them to participate.

The research outcomes suggest that the quantitative survey items may not be sensitive enough to capture context-specific differences between groups of volunteers. Qualitative responses helped to provide context and more in-depth information on how behaviors, interests, and motivations between volunteers changed over time. While long- and short-term volunteers scored similarly on the Interest in Nature Scale, qualitative analysis revealed that experienced volunteers engaged in broader range of science-based activities. Similarly, on the Motivation for Participation in Citizen Science Scale, qualitative analysis revealed differences in the reasons for initially joining Blue Thumb, and the reasons for continued participation. This qualitative information was important to consider in addition to quantitative survey items in order to fully understand participant outcomes achieved through Blue Thumb.

The findings of this research present several implications for evaluation design in citizen science assessments. First, volunteers that join citizen science programs have already high levels of pro-environmental behaviors, interests, and motives driving their decision to volunteer. In the context of Blue Thumb, these outcomes may be better predictors of volunteer retention than defined outcomes or goals to be achieved. As seen in this research and previous studies, volunteer motivation and interests were found to be compounded variables that are influenced by multiple factors and capable of changing overtime. New directions in evaluation research might include more in-depth longitudinal studies of select participant outcomes to show differences in, or the evolution of, outcomes throughout the entire volunteer experience. Future evaluation should include assessment of volunteer trainees who choose not to continue participation in a citizen science program to establish if their levels of behavior, interest, and motivation widely differ from continuing participants.

In this study, there were few significant differences in self-reported survey items. While self-reported data from pre-established scales and survey items is among the most common method of evaluating participant outcomes currently (Peter et al., 2019), there is significant debate around the validity of self-reported assessments of environmental behaviors and motivations (Broassard et al., 2019; Chase & Levine, 2018; Somerwill & When, 2022). In this research, volunteer qualitative responses did not confirm some quantitative survey findings, and often revealed additional information that was vital for full understanding of participant experience. This calls attention to the highly context-dependent nature of evaluation. Generalized and broad questions about behaviors, interests, and motivations may be useful for comparisons across citizen science programs, but they may not fully capture or account for the contextual differences within each citizen science program (Braun & Dierkes, 2019). Scale items and surveys must be flexible in nature, for ease of practitioner use and applicability to a wide range of interdisciplinary programs.

This research informs best practices for citizen science program administrators by highlighting how volunteers' interests and motivations sustain participation and engagement within citizen science programs. This research suggests that retention of volunteers long-term may depend on the levels of pro-environmental behaviors, interests, and motivations volunteers have before joining a citizen science program, and how these factors change throughout their volunteerism. Program administrators may be able to sustain high levels of interest and motivation by tailoring volunteer projects to highlight specific volunteer interests, such as providing resources for volunteers to investigate their own research questions or providing open-sourced data for volunteers to probe. In terms of changing environmental behaviors, the evaluation illustrates that BT volunteers were influenced by the content and suggestions offered in the training specific to water quality.

Place-based Motivations for Volunteer Participation

While there have been many studies that attempt to understand the motivations of volunteerism broadly, there have been fewer that attempt to research the motivations specific to environmental monitoring in citizen science (Bruyere & Rappe, 2006; Domroese et al., 2017; West & Pateman, 2016). Fewer still have assessed the role of sense of place, or the attachments between volunteers and the physical locations that they monitor, to volunteer motivation to continue engaging in citizen science. This research explored Blue Thumb participants' place attachment and place meaning to the specific streams they monitor, and how this connection to place influenced their motivation, using a previously established Place Attachment Model (Haywood et al., 2021; Raymond et al., 2010).

The second question was, How does place-based volunteerism influence differences in participation, motivation, and experience? Place played an important role in Blue Thumb volunteers' decision to continue participating, and the value that they attributed to their volunteerism. For those who participate in Blue Thumb, the stream sites that they monitor are places that hold multiple meanings and motivate volunteers in different ways. Many volunteer attachments to place depended on volunteer demographics such as location in state, educational or career background in science, or age/level of experience.

Broadly, this research helps to investigate the complexity of volunteer motivations and their impact on how, when, for how long, and why they continue to engage in a specific citizen science project. Application of the PAT model highlighted how volunteers are inspired to monitor environmental locations, the dimensions of this connection to place, and ties to participant outcomes. Motivations and attachment to place were categorized into three dimensions: personal attachment, community attachment, and natural environmental attachment. Personal motivations ranged from feelings of connectedness between the volunteer and specific places, to attachments to place based on volunteers' personal or educational background. Community motivations to place centered on volunteers' desire to spread education and awareness. These types of attachments are driven by creation and maintenance of social relationships through volunteerism and building a sense of community in Blue Thumb. Lastly, environmental motivations related to love for being outdoors and experiencing wildlife, while also engaging in the process of scientific inquiry.

This research validates the changes Haywood et al. (2020) made to the PAT model to include a science affinity construct, defined as the connection between volunteer and place through the practice of science and general knowledge of that place. Volunteers reported that feelings of place attachment were often linked to the process of scientific inquiry, with volunteers making observations, asking questions, and investigating the places they monitored. Further, volunteers expressed that involvement in the data interpretation and dissemination process was important for their motivation to continue monitoring in these places. These findings suggest that environmental monitoring citizen science programs possess the ability to engage volunteers in the scientific inquiry process, and that these experiences combined with the places they are had are important to volunteer motivations.

For this study sample, most participants were volunteers with established and familiar stream sites who had already completed several months of monitoring. Additional study would benefit from investigating how attachments to place shift throughout the entire volunteer experience, from initially joining to repeated visits at a monitoring site. Study participants were asked about barriers that discouraged them from more participation. Concern about site accessibility was common for older volunteers. For environmental programs, consideration about the "places" that are monitored may need to be expanded. Whether a stream that is isolated in the woods, or a stream located directly off the highway, there should be a balance between the scientific needs of the citizen science program and the accessibility needs of the volunteer (Morales et al., 2020). Volunteers also strongly indicated that communication from the BT program was important to their decision to continue participating, especially in regard to what data was collected and how it was used. Volunteers would like more explanation about the importance of collecting environmental data and transparency about how the data may be used.

In sum, the reasons why volunteers join and stay involved in a citizen science project have an impact on long-term retention. Understanding volunteer motivations can aid citizen science project managers in a) reducing the time and effort spent on volunteer recruiting and retention while b) optimizing the advantages of volunteers' involvement for both participants and the project. Volunteers' motivation to participate in the program was mostly based on both their experiences in the natural world, and connections made to their community, which has design implications for outdoor-based citizen science initiatives. The findings of this study suggest that building a sense of community by connecting volunteers across vast geographical areas of study is important to volunteers. Considering these findings, managers of environmental citizen science programs should continue to use the environment, and connections between people and place, as the foundation from which to further build volunteer experiences.

Supporting Data Quality Through Self-Efficacy and Skill

The majority of scholarship about environmental citizen science outcomes has focused on describing and validating the accuracy and credibility of volunteer collected data (Ottinger, 2010; Peckenham and Peckenham., 2014; Haywood 2014; Muenich et al., 2016). While monitoring data is essential for resource management, citizen collected data has often been challenged and perceived by scientists as non-credible (Stepenuck & Genskow, 2018). It is important to recognize that more factors than collection method alone may influence data quality. Participant outcomes, such as perception of skill acquisition, reasons for participation, level of engagement, and belief in one's own abilities (self-efficacy), may impact the quality of data collected.

This study asked, What are participants' perceptions of self-efficacy and scientific skills and how do these outcomes relate to data quality? Comparison of volunteers across different lengths of participation did not reveal significant differences in the level of perceived self-efficacy or skill. During interviews, volunteers attributed overall high levels of confidence due to successful training and oversight from the program administrators throughout the process of their data collection. There was no significant differences detected in volunteer measured water quality values for chloride, nitrate, or pH during quality assurance testing between different length groups, excluding temperature. These findings suggest a need for further research to understand the relationship between self-efficacy, skill, and data quality.

Moderate to strong correlations were found between how volunteers perceived their self-efficacy and skill, and the accuracy of the data they reported for nitrate and temperature.

Relationships in perception and accuracy were positive for nitrate, indicating that as volunteers expressed higher confidence in their nitrate testing skills, they had less error. However, a strong positive correlation was found between how volunteers perceived their skill level and the amount of error during temperature measurements. That is, volunteers with the highest self-efficacy for measuring temperature had the most error in their actual measurements. During interviews, volunteers were most confident about temperature, and described it as “easy”, “common sense”, yet had the highest amount of error on this test. This finding suggests that there may be differences between how volunteers perceive their skill and the actual level of skill they demonstrate. It is unclear if volunteers' accuracy on these measures may be affected by personal factors and perceptions.

The results of this research confirm that combined quality assurance protocols and thorough oversight from project managers helps to increase volunteer confidence in data collection and overall accuracy. In chapter one, the annual volunteer data collection experience was aligned with the experiential learning cycle. Each year volunteers attend two water quality testing events and reflect on how to follow protocols and best-practices in data collection, then apply this when returning to field monitoring. The Volunteers reported that this practice and hands-on approach increased their confidence, improved their skills, and encouraged them to continue collecting samples.

These results emphasize the value of further study into the connection between self-efficacy and data collection abilities. One consideration for program managers is the type of instrumentation used in monitoring. Volunteers were less confident with their data and skill of interpretation with qualitative or subjective instrumentation, such as a color change used to interpret chloride. Results of quality assurance testing indicated higher levels of variation and error in sampling these parameters. The volunteers expressed a desire for more objective and standardized equipment to help decrease ambiguity of results and increase confidence in data collection/interpretation. The results of this study highlights a need for additional research into how volunteers' self-efficacy and data quality are affected by monitoring equipment.

Confidence in monitoring was attributed to factors such as program training, practicing sampling techniques with project managers, and provided resources (i.e., instructional videos and pamphlets). For program managers, providing volunteers ample opportunity to hone project specific skills lead to increase confidence in data collection and skill using project-specific equipment. Citizen science programs should think carefully about the experiential learning cycle and consider developing additional resources for volunteers (such as apps, handbooks, downloadable instructions, data collection protocol videos, and "how-tos”) for both instruction and field collection.

Limitations

One of the most important components of study design is validity, or the degree to which measured variables reflect what they are intended to measure. This study has limitations that affect internal validity. While the Cornell Scales were useful to provide a baseline of comparison, modifications had to be added to make survey items context-specific for Blue Thumb volunteers. Creating new questions and customizing existing scales means that the results of this study are not directly comparable to other studies using the same scales.

The findings of this research further suggests that shared frameworks for evaluation and common tools are needed, but with consideration and flexibility. While the use of uniform measures and survey items enables for comparison across citizen science projects, broad or generalized survey items may miss important context-specific information relevant to each citizen science program. Additionally, this study also revealed the importance of mixed methodology in the process of programmatic evaluation: specifically adding qualitative assessments to provide context for quantitative findings. Pre-post survey questions have been utilized in previous evaluations to measure participant outcomes, but qualitative data may provide more context-specific information, as shown by the study's findings.

This research represents one case study limiting the generalizability of the results to a wider audience. Due to the complexity of the phenomenon being examined and the makeup of the research questions, it was determined that a multi-phase mixed methods design was the best option for evaluation. Onwuegbuzie and Johnson (2006) created a typology of mixed methods legitimation that were used to identify two sources of limitation due to mixed methodology. First, inside-Out is defined as "the extent to which the researcher accurately presents and appropriately utilizes the insider's view and the observer's view". To legitimize this, participants were given summaries of their results and the ability to provide their own feedback on both sides of the issue. Secondly, there is political legitimation, defined as "the extent to which the consumers of mixed methods research value the meta-inferences stemming from both data methodologies". There is the tendency in evaluations to value quantitative data over qualitative data. This research advocated for a pluralistic approach to methodologies by engaging with Blue Thumb administrators throughout the evaluation process, from attending and monitoring training and quality assurance events to on-going reflective discussions about the type of evaluation being conducted.

Conclusion

By using a common framework for evaluation and developed survey tools (Phillips et al., 2018 framework and DEVISE survey items), this study contributed to the discussion about citizen science evaluation design. Whereas earlier evaluations frequently relied on freshly developed instruments, citizen science assessments are using new and evolving shared evaluation frameworks and survey items. One goal of this study was to investigate new methodologies for assessing and evaluating this expanding field of study. As demonstrated in this paper, more research is needed into meaningful uses quantitative and qualitative assessment tools and techniques to accurately capture the full influence of volunteerism on participants.

Despite widespread agreement on the need of evaluation, the field of citizen science faces challenges in assessing learning and engagement results on theoretical, technical, and even practical levels. This dissertation contributed to the field of citizen science evaluation in three main ways. First, the experiential learning cycle established by Kolb proved beneficial as a theoretical framework in this study to understand how participant outcomes are obtained through ongoing volunteer experiences. Second, this research highlighted the potential for qualitative research and mixed methodologies to be included for more accurate and complete evaluation of citizen science volunteers. Finally, the evaluation process included in this study was intended to show citizen science program administrators how assessing participant outcomes and volunteer experience can be valuable for program design, as well as volunteer recruitment, engagement, and retention efforts.

Evaluation of participant outcomes is useful not just for academics to understand how volunteerism affects participants, but also for citizen science program managers to consider when developing or maintaining specific projects. As the field of citizen science expands and evolves, it is crucial to remember that volunteers are the foundation that allows it all to happen. Volunteers in environmental citizen science projects not only offer large amounts of spatial and temporal data that is important for conservation and natural resource management initiatives, but they are also influenced in turn by the experiences and locations they visit while participating. Continuous and reflective evaluation of volunteer experiences, perceptions, and outcomes is critical to the long-term viability of citizen science activities.

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APPENDICES

APPENDIX A: BEHAVIOR, INTEREST, AND MOTIVATION SURVEY

Note: questions with an asterisk * sign denote modified questions that were given to experienced volunteers only.

Q1 What is your name? If you do not want to share, leave this question blank. If you do share your name, you may be asked to participate in a future follow-up survey. This is completely optional.

Q2 Can you tell us a little about yourself?

Q3 What is your age?

Q4 What city and state are you from?

Q5 What is your highest level of education? Circle your answer below.

Some K-12 School High School or Equivalent

Technical Certificate Some College

Associate Degree Bachelor Degree

Master Degree Doctorate Degree

Q6 Please identify whether you fall into one of the categories of career/interest groups below. Circle your answer below. If you do not fit these categories, please circle and answer the "other" box.

College Professor College Student

K-12 Teacher K-12 Student

Part of a Group (please identify which) Landowner

Government Employee (please identify which) Scientist

Q7 How did you learn about Blue Thumb?

Q8 Why did you sign up for Blue Thumb's training?

*****Why did you originally sign up for Blue Thumb?*

Q9 What benefit do you see from participating in Blue Thumb's training?

*How long and in what ways have you been participating in Blue Thumb?

Q10 What types of environmentally minded actions do you take in your normal life?

How do you feel your actions and attitudes towards the environment have changed since you began participating in Blue Thumb?

Q11 Now that you have successfully completed a training, what are things you can do to protect water quality?

What are ways Blue Thumb has influences action you take to protect water quality?

Q12 What kinds of environmental events would you be interested in participating in? Circle all that apply.

What kinds of environmental events have you participated in since joining Blue Thumb?

Scientific Conferences

Creek Clean Up Events

BioBlitz Events

Public Education Events

Earth Day Celebration

Workshops

Library Presentations

Other

	I don't do this	I am thinking of doing this	I used to do this	I intend to do this	I am currently doing this	I will continue to do this	I can't imagine NOT doing thi
Choose not to use fertilizers	1	2	3	4	5	6	7
Choose not to use pesticides	1	2	3	4	5	6	7
Use less water in and around the home	1	2	3	4	5	6	7
Regularly pick up litter	1	2	3	4	5	6	7
Reduce use of toxic household products	1	2	3	4	5	6	7
Participate in environmental efforts	1	2	3	4	5	6	7

Q13 For the following statements, please rate the extent to which you do or don't take part in these activities by putting an "X" in the appropriate response in each row/circling the correct number.

Q14 Which aspect of stream monitoring or water quality did you find the most interesting during training and why?

Which aspect of stream monitoring do you find the most interesting and why?

Q15 Rank Blue Thumb's activities from the training by writing a number in the space on the left according to which interested you the most (ranked highest -1) to which interested you the least (ranked lowest - 5).

______ Enviroscape
______ Macroinvertebrate Collection
______ Other:
______ Project WET Activities
______ Water Quality Monitoring

Q16 Please describe your main motivations for participating in Blue Thumb and monitoring a stream in your own words

Q17 Please indicate how much you DISAGREE or AGREE with each of the following statements regarding your interest in various topics by putting an "x" or circling the

appropriate column. Please respond with how you really feel, rather than how you think "most people" feel.

	Strongly agree	**Somewhat agree**	**Neither agree nor disagree**	**Somewhat disagree**	**Strongly disagree**
I want to learn more about aquatic biological science (macroinvertebrates, fish)	1	2	3	4	5
I want to learn more about aquatic physical science (water chemistry, physics, geology)	1	2	3	4	5
I want to understand how processes in nature work (why water quality changes, how organisms respond to pollution)	1	2	3	4	5
I am very interested in the natural sciences	1	2	3	4	5
I like to make observations in nature (animals, plants, sounds, etc)	1	2	3	4	5
I like to engage in science-related hobbies	1	2	3	4	5
I am interested in looking at stream data, from either my own stream or Blue Thumb's data	1	2	3	4	5
I am interested in using my stream data to make tables, graphs, or a summary report	1	2	3	4	5

Q18 Please indicate how much you DISAGREE or AGREE with each of the following statements by putting an "X" in the appropriate response column/circling the correct number.

Think about some of the reasons you decided to join Blue Thumb or to monitor a stream. Why do you do these things?	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Because I think it is a good idea to do something for water quality in Oklahoma	1	2	3	4	5
Because I am concerned what could happen to people I care about if I don't do anything	1	2	3	4	5
Because I enjoy doing it	1	2	3	4	5
Because I think it is a good idea to educate people on water quality	1	2	3	4	5
Because I would feel guilty if I didn't do anything about water quality	1	2	3	4	5

Because I am concerned about what could happen to water quality if I don't do anything	1	2	3	4	5
Because it is fun to do	1	2	3	4	5
Because I want to be seen as a good or caring person	1	2	3	4	5

Q19 Please indicate how much you DISAGREE or AGREE with each of the following statements by putting an "X" in the appropriate response column/circling the correct number.

In general, why do you choose to learn and understand water quality topics?	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Because I like learning about water quality	1	2	3	4	5
For the recognition or respect I'll get from others	1	2	3	4	5
Because I am required to understand water quality	1	2	3	4	5
Because people I look up to think it's good to learn about water quality	1	2	3	4	5
Because understanding water quality will help me achieve things that are important to me	1	2	3	4	5
Because it's fun to learn about water quality	1	2	3	4	5
Because I want others to think I'm good at understanding water quality topics	1	2	3	4	5
Because I believe that understanding water quality will help me in some way	1	2	3	4	5

Q20 Please indicate how much you feel you know about the following topics by putting an "X" in the appropriate response column/circling the correct number.

	A great deal	A lot	A moderate amount	A little	None at all
Which Blue Thumb events or programs I can participate in	5	4	3	2	1
How to collect macroinvertebrates	5	4	3	2	1

Which Blue Thumb educational tools are available	5	4	3	2	1
How to perform water quality monitoring protocols	5	4	3	2	1
How to use or interpret my water monitoring data	5	4	3	2	1
How to collect accurate, high-quality data	5	4	3	2	1
Issues and pollutants that influence water quality	5	4	3	2	1

Q21 What new things did you learn about water quality and management that you did not previously know?

*Since beginning to monitor a stream, what new things have you learned?

Q22 Which of the Blue Thumb activities listed below are you most likely to participate in? You may circle more than one option.

Monthly Newsletter

Attending Educational Events

Use Data for Interpretation

Monitoring a Stream Monthly

Creek Clean Up Events

Other

Q23 Do you plan to participate in Blue Thumb alone or as part of a group?

Q26 How have your interests in water monitoring, stream education, or participation in Blue Thumb changes from when you first started to now?

Q27 How has your motivation for participating in Blue Thumb changes, if at all, from when you first started to now?

Q28 What makes you more motivated to participate in water monitoring?

APPENDIX B: MOTIVATION AND PLACE INTERVIEW PROTOCOL

Interview Protocol

Duration: 1 hour
Protocols:

1. Participants will be handed a copy of the consent form and informed verbally about the option to participate in the study. The interviewer will describe the goals of the current research, and how the participants' responses will be recorded and kept (see script below).
2. Once a participant has signed the consent form, the interviewer will acknowledge that they are about to begin asking questions. A recording device will be used to capture audio while the interviewer takes notes. The participant will be made aware of both methods used to capture information during the interview.
3. A list of questions is provided for both the interviewee and the interviewer to guide the discussion; however, the interviewer may follow up with specific questions or probe for answers depending on the responses of the interviewee.
4. At the end of the interview, the interviewer will thank the interviewee for their time and ask if there is anything that the interviewee would like to know.

"To facilitate our note-taking, we would like to audio tape our conversations today. Please sign the release form. For your information, only researchers on the project will be privy to the tapes which will be eventually destroyed after they are transcribed. In addition, you must sign a form devised to meet our human subject requirements. Essentially, this document states that: (1) all information will be held confidential, (2) your participation is voluntary and you may stop at any time if you feel uncomfortable, and (3) we do not intend to inflict any harm. We have planned this interview to last no longer than one hour. During this time, we have several questions that we would like to cover. Thank you for your agreeing to participate"

Introduction

You have been selected to speak with us today because you have been identified as someone who has a great deal to share about your involvement with Blue Thumb. Our research project on a whole focuses on what motivates volunteers to participate in water quality monitoring, and how volunteers feel about the place they monitor (specifically the streams they visit). The goal of this research is to inform citizen science programs, like Blue Thumb, about their volunteer base and help to generate information that programs can use to improve upon volunteer experience.

Interviewee Background

1. Can you tell me a little about yourself, in terms of your job or hobbies?
2. How long have you been involved with Blue Thumb?

    1. Probes: In what ways have you been involved with Blue Thumb? Do you participate in more than stream monitoring?

Place Based Questionnaire

1. Can you tell me a little bit about the site that you monitor?
    1. Probes: Do you monitor this site alone or with others? How long have you monitored this site? How often do you visit this site? What does this site mean to you?
2. Do you think the community has any kind of reliance or dependence on this site for anything, like fishing or drinking water?
    1. Probe: Do you, personally, rely on this body of water for anything?
3. What kind of emotions, if any, do you have about this site?
    1. Probes: Do you have any kind of personal attachment to this site? How have your feelings about the site changed, if at all, over time?
4. Can you share with me any memories about sampling at this site that stand out to you?
    1. Probes: Has anything happened while sampling here that was meaningful or unusual in any way?

Motivation Questionnaire

1. What is your strongest motivator for participating in Blue Thumb?
    1. Probes: Has your reason for participating in Blue Thumb changes since you first began to the present time?
2. Why is monitoring water quality important to you?
3. Does the specific site you monitor have any influence in your motivation for continuing to participate?
4. Has your experience with monitoring this site led you to do any other kind of environmentally minded volunteerism or activities?
5. Are you satisfied with your volunteering experience, or is there anything more that Blue Thumb could provide that would encourage or motivate you even more?
    1. Probes: Is there anything about the training, Blue Thumb, or your experiences at your specific site that have discouraged you from participating?

Wrap-Up

1. Do you have any questions for the evaluator, or for Blue Thumb?
2. What are your final thoughts about what was discussed today?

APPENDIX C: BLUE THUMB QUALITY ASSURANCE TEST SHEET

Oklahoma Blue Thumb

Quality Assurance Session

Spring, 2022

____

Name and Date

____

Stream Site, County

pH ________ Lot # ________

NO_3-N ________mg/L Lot # ________

NH_3-N ________mg/L Lot # ________

PO_4-P ________mg/L Lot # ________

Cl ________mg/L Dry Lot # ________ Liquid Lot # ________

DO ________ #1 Lot ________#2 Lot ________#3 Lot ________

Starch Lot ________ Sod. Th. Lot ________

Water temperature ________°C

1. Why is it important to monitor the same time of day each time you monitor?

2. What is the purpose of triple rinsing your equipment?

3. Today if your monitoring day, but it is raining. Should you still go out and monitor or wait a day or two? Why?

APPENDIX D: SELF-EFFICACY AND SKILL SURVEY

Blue Thumb Participant Survey: Skill and Efficacy

Please write your name below if you consent to the survey and are interested in a potential follow up interview:

Demographics

1. Can you tell us a little about yourself?

2. How do you identify your gender?

3. What is your age?

4. Which city and state are you from?

5. What is your highest level of education?
    a. Some K-12 School
    b. High School or equivalent
    c. Technical certificate
    d. Some College
    e. Bachelor degree
    f. Associate degree
    g. Masters degree
    h. Doctorate degree

6. Please identify whether you fall into one of the categories below. If not, please fill in the "other" column.
    a. College Professor
    b. College Student
    c. K-12 Teacher
    d. K-12 Student
    e. Part of a Group (please identify which): _________________________
    f. Landowner
    g. Government Employee (please identify which agency): ____________________
    h. Scientist
    i. Other: _______________________

Skill

Please indicate how much you DISAGREE or AGREE with each of the following statements by circling the number in the appropriate column. Please respond as you really feel, rather than how you think "most people" feel.

Begin each statement below with: "I currently have the skills necessary to…"

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Closely observe/record data	1	2	3	4	5
Accurately identify species or issues related to my project.	1	2	3	4	5
Understand the data collection protocol.	1	2	3	4	5
Successfully submit my observations to the project database.	1	2	3	4	5
Collect data in a standardized manner.	1	2	3	4	5
Use the project database to answer a question.	1	2	3	4	5
Interpret the meaning of project data presented in maps, charts, graphs, etc.	1	2	3	4	5
Conduct statistical analyses using project data.	1	2	3	4	5
Use project data as a source of evidence.	1	2	3	4	5
Design a study related to project data.	1	2	3	4	5

Communicate project findings to others	1	2	3	4	5
Train others to participate in the project.	1	2	3	4	5

Please indicate how much you DISAGREE or AGREE with each of the following statements by circling the number in the appropriate column. Please respond as you really feel, rather than how you think "most people" feel.

Begin each statement below with: "I currently have the skills necessary to…"

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Record physical habitat data	1	2	3	4	5
Take stream temperature readings	1	2	3	4	5
Read and interpret a secchi disk					
Perform dissolved oxygen test	1	2	3	4	5
Perform nitrate test	1	2	3	4	5
Perform phosphate test	1	2	3	4	5
Perform chlorine test	1	2	3	4	5
Perform ammonia test	1	2	3	4	5
Interpret my data	1	2	3	4	5
Collect high quality data	1	2	3	4	5

Self-Efficacy for Learning and Doing Citizen Science

Please indicate how much you DISAGREE or AGREE with each of the following statements by circling the number in the appropriate column. Please respond as you really feel, rather than how you think "most people" feel.

These statements are about how you feel about learning and understanding science topics, as well as how you feel about doing scientific activities.

Choose one answer in each row	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
I think I'm pretty good at understanding water quality topics.	1	2	3	4	5
Compared to other people my age, I think I can quickly understand new topics about water quality.	1	2	3	4	5
It takes me a long time to understand new topics about water quality.	1	2	3	4	5
I feel confident in my ability to explain water quality to other people.	1	2	3	4	5
I think I'm pretty good at following instructions for monitoring water quality.	1	2	3	4	5
Compared to other people my age, I think I can monitor water quality pretty well.	1	2	3	4	5
It takes me a long time to understand how to correctly monitor water quality.	1	2	3	4	5
I feel confident about my ability to explain how to monitor water quality to others.	1	2	3	4	5

Self-Efficacy for Environmental Action

Please indicate how much you DISAGREE or AGREE with each of the following statements by circling the number in the appropriate column. Please respond as you really feel, rather than how you think "most people" feel.

Choose one answer in each row	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
I feel confident in my ability to help protect waterways in Oklahoma.	1	2	3	4	5
I am capable of making a positive impact on local streams.	1	2	3	4	5
I am able to help take care of water quality.	1	2	3	4	5
I believe I can contribute to solutions to water	1	2	3	4	5

quality problems with my actions.					
Compared to other people, I think I can make a positive impact on water quality issues.	1	2	3	4	5
I don’t think I can make any difference in solving water quality issues.	1	2	3	4	5
I believe that I personally, working with others, can help solve water quality issues.	1	2	3	4	5
It’s hard for me to imagine myself helping to protect local streams.	1	2	3	4	5

APPENDIX E: SKILL AND EFFICACY INTERVIEW PROTOCOLS

Blue Thumb: Self-Efficacy, Skill, and Data quality

Interviewee: ______________________ Interviewer: Cheyanne Marie Olson

Date of Interview: __________ Location:

Supplies

___ Notepads

___ Participant Questions

___ Questions (Moderator Script)

___ Recording Device Duration: 15 minutes

Protocols

1. Participants will be handed a copy of the consent form and informed verbally about the option to participate in the study. The interviewer will describe the goals of the current research, and how the participants' responses will be recorded and kept.
2. Once a participant has signed the consent form, the interviewer will acknowledge that they are about to begin asking questions. A recording device will be used to capture audio while the interviewer takes notes. The participant will be made aware of both methods used to capture information during the interview.
3. A list of questions is provided for both the interviewee and the interviewer to guide the discussion, however, the interviewer may follow up with specific questions or probe for answers depending on the responses of the interviewee.
4. At the end of the interview, the interviewer will thank the interviewee for their time and ask if there is anything that the interviewee would like to know.

Introduction

You have been selected to speak with us today because you have been identified as someone who has a great deal to share about your involvement with Blue Thumb. Our research project on focuses on how volunteers feel about their confidence in project specific skills, and the quality of data they collect. The goal of this research is to inform citizen science programs, like Blue Thumb, about their volunteer base and help to generate information that programs can use to improve upon volunteer experience as well as improve volunteer collected data.

Self-Efficacy Questionnaire

1. How confident do you feel overall that Blue Thumb volunteers collect high quality and accurate data?

2. How confident do you feel that you, personally, collect high quality and accurate data?

3. Can you describe any obstacles you perceive that might **prevent you** or others from collecting high quality data?

4. What would encourage or help you to feel more confident in your data collection?

Skill Questionnaire

1. Which water quality monitoring skill or technique do you think you are the best at?

2. Which water quality monitoring skill or technique do you struggle with?

3. What are ways that Blue Thumb **has increased** your environmental monitoring skill level?

VITA

Cheyanne Marie Olson

Candidate for the Degree of

Doctor of Philosophy

Thesis: A MIXED METHODS EVALUATION OF A WATER-MONITORING CITIZEN SCIENCE PROGRAM

Major Field: Environmental Science

Biographical: Cheyanne Olson was born in Arkansas in 1993. Her father, mother, and younger sibling traveled and lived across many states during her childhood. They settled in Saint Helens, Oregon during her high school years. Cheyanne became actively involved in environmental volunteering, first through an environmental science class at her high school and later through a county office. She collected water quality readings on a stream that ran by her house. Later, she participated in Oregon Museum of Science and Industry's summer camp called "Salmon Camp", where she learned about salmon conservation in the Pacific Northwest. She presented her findings on the stream near her house at a national science fair at RIT in NY and won. This sparked a lifelong journey to learn more about water, and the ways people interact with it.

Education:
Completed the requirements for the Doctor of Philosophy in your Environmental Science at Oklahoma State University, Stillwater, Oklahoma in May 2023.
Completed the requirements for the Master of Science in your Environmental Science at Texas A&M University, Corpus Christi, Texas in 2017.
Completed the requirements for the Bachelor of Science in your Fish and Wildlife Biology at Northeastern State University, Tahlequah, Oklahoma in 2015.

Experience:
Biology Instructor at Rogers State University 2018 – Present
Board member for Friends of Blue Thumb 2023 – Present

Professional Memberships:
Association for the Sciences of Limnology and Oceanography
Citizen Science Association
Ecological Society of America
National Science Teacher Association
Oklahoma Academy of Science